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Woods Hole Oceanographic Institution

Sedimentation Study
Environmental Monitoring and Operations Guidance System (EMOGS)

Kings Bay, Georgia and Florida
1988-1990

Final Report

by

D. G. Aubrey, T.R. McSherry and W. D. Spencer

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Funding was provided by the National Oceanic & Atmospheric Administration's Sea Grant Program through Grant NA860A-D-SG090.

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Approved for Distribution:

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LIST OF SYMBOLS

V	Total volume of ebb tide delta
P	Spring tidal prism
A_c	Inlet cross-sectional area
W	Inlet width at throat
D	Inlet depth at throat
a_o	Ocean spring tidal amplitude
H_s	Significant wave height
T_w	Weighted mean wave period
θ_w	Incident peak wave heading
T_p	Modal wave period
A_p	Activity parameter
$\bar{z}$	Sample mean
$\sigma^2{}_z$	Variance of sample
γ_z	Skewness coefficient for sample
β	Kurtosis coefficient
q_b	Bedload sediment discharge
ζ	Sand level
U	Mean steady near-bed current
$\hat{u}_b$	Maximum near-bed wave orbital velocity
θ_t	Steady current direction
ρ_s	Sediment density
ρ_w	Water density

SEDIMENTATION STUDY
ENVIRONMENTAL MONITORING AND OPERATIONS GUIDANCE SYSTEM (EMOGS)
KINGS BAY, GEORGIA AND FLORIDA
1988-1990
FINAL REPORT

DAVID G. AUBREY, DIRECTOR
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1. SUMMARY

Repeated side-scan sonar and multi-frequency bathymetric surveys, accompanied by accurate, high resolution, and repeatable navigation, were conducted in the vicinity of a tidal inlet to define the length and time scales associated with bedforms and channel shoaling in a structured tidal inlet. The study site, St. Marys entrance channel along the Georgia/Florida border (Fig. 1), has a dredged channel approximately 46-52 feet in depth at a datum of mean low water (MLW), bordered by a large ebb tidal delta. The tidal inlet serves Cumberland Sound, Kings Bay, and associated waterways, providing a large discharge of water from the inlet that creates bedforms and channel shoaling, given the abundance of sand-sized sediment in the vicinity. The jettied inlet produces flows that are predominantly tidally-driven, whereas farther offshore the driving forces consist predominantly of waves and storm-generated flows. In the channel reaches (Table 1) between these two areas, combined wave/steady flows are present, creating a myriad of scales of bedforms and shoaling patterns. This study was designed to elucidate the time and space scales of these variable bedforms and shoaling patterns, emphasizing the difference in these scales between the three different flow regimes. The results provide an important data base for quantifying shoaling processes and mechanisms in tidal inlet channels.

During phases I-III, thirteen bathymetric and side-scan sonar surveys were accomplished. Dredging activity during the period created major changes to the channel, making comparison of differences in channel bathymetry ambiguous. Similarly, comparison of channel bedforms was difficult because many of the forms were not fully developed following dredging. Comparisons of bedforms in areas outside and adjacent to the channel over different surveys are less ambiguous. Because these data were all acquired during years when storms were mild, excessive sedimentation rates were not observed. However, experience elsewhere and a numerical sediment transport model suggest much higher sedimentation rates will occur during major storms.

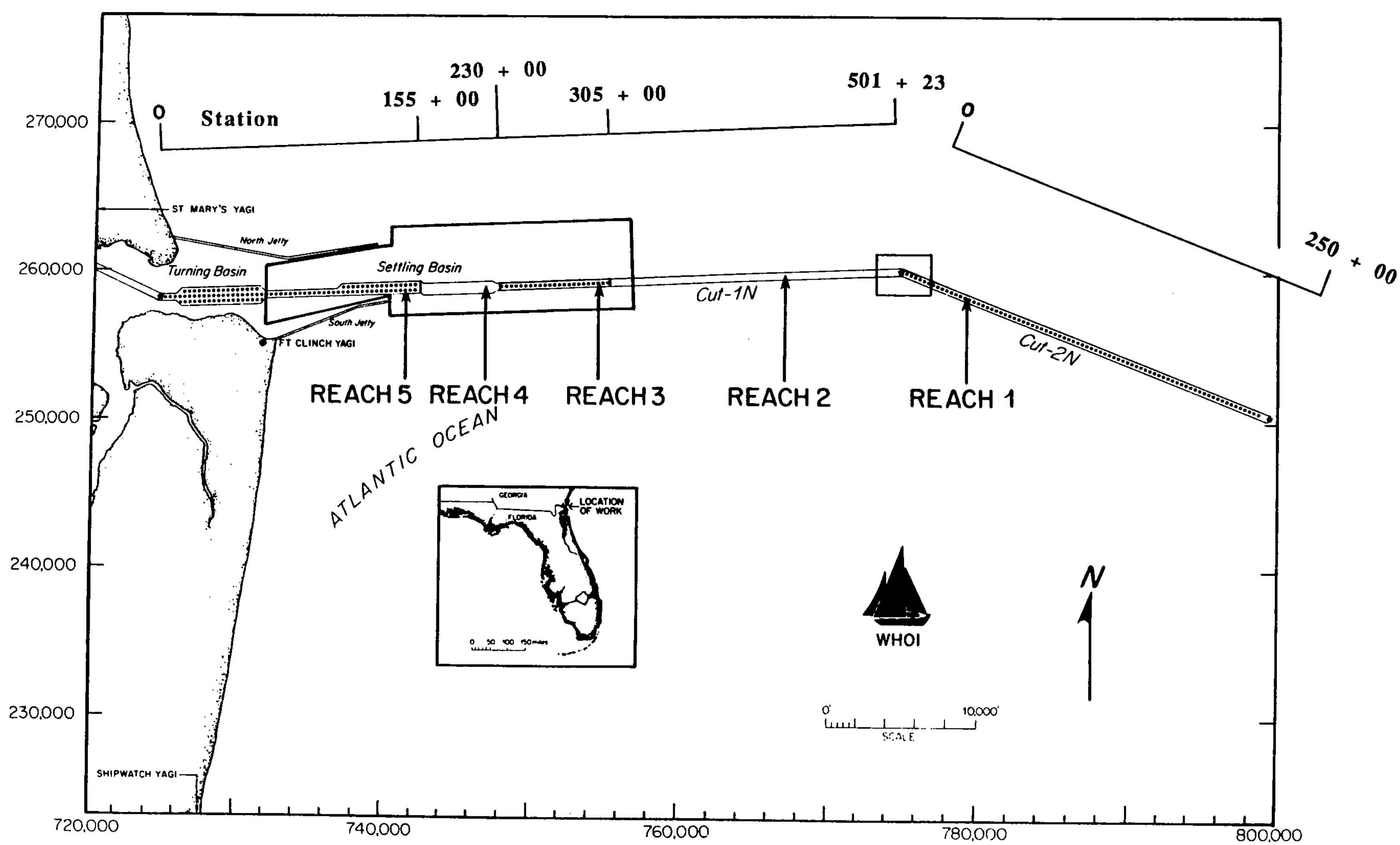


Figure 1. Survey area along the St. Mary entrance channel.

Phase I-III data indicate the following conclusions:

a) Changes in bathymetry occur within and outside the channel on various time and space scales.
b) Bedforms of various scales occur in and outside of the channel. Within the channel, bedforms occur commonly, having heights of 2-3 feet and possibly higher. Outside the channel, bedforms (shoals) reach more than 10 feet higher than the ambient delta depths.
c) Shoaling rate is greatest along the north margin of the channel.
d) The locations of shoals on the ebb tidal delta suggest slow but continued migration of these bedforms to the south, towards the dredged channel. This has been the primary source of channel sedimentation to date.
e) Hotspots where sedimentation rates appear highest are concentrated on the ebb-tidal delta (stations 255+00 to 265+00), just outside and just inside the jetties (from near station 135+00 to near station 230+00), and near navigation buoy #12 (stations 400+00 to 450+00). A sedimentation monitoring program emphasizing periodic hotspot surveys from a surface vessel is suggested to guarantee adequate information about channel depths for the EMOGS program , particularly during periods of extreme waves (heights >4 m).

2. INTRODUCTION

St. Marys entrance channel, segmented into 5 defined reaches (Table 1), connects the Atlantic Ocean with Cumberland Sound, and is located on the border between Georgia and Florida (Fig. 1). Previous work in this region has been done by Olsen (1977), Parchure (1982), Aubrey (1986), Aubrey *et al.* (1987), Marino (1986), and Vermulakonda *et al.* (1988). Marino (1986) has summarized earlier work, listing the important physical parameters of the system (Table 2). The large spring tidal prism creates strong flows within the inlet (up to 1.5 m/sec), which are ebb-dominated in the main channel. Abundant sand-sized and smaller sediment within the estuary and nearshore contributes to the build-up of the large ebb tide delta, which has grown significantly since man's influence has increased over the past half-century, primarily through construction of the jetties protecting the inlet entrance (Olsen, 1977).

TABLE 1
REACHES DEFINED FOR ST. MARYS ENTRANCE CHANNEL

REACH	START	END
1	Cut 2-N 000+00	Cut 2-N 250+00
2	Cut 1-N 305+00	Cut 1-N 501+23.68
3	Cut 1-N 230+00	Cut 1-N 305+00
4	Cut 1-N 155+00	Cut 1-N 230+00
5	Cut 1-N 7100	Cut 1-N 155+00

Whereas steady currents dominate flows within the inlet itself, past work (Aubrey, 1986; Aubrey *et al.*, 1987) has shown that waves become more dominant on the margins of the ebb tide delta. The geometry of the system combined with its exposure to open waves and a spring tidal range of 2.1 m dictates the interesting flow patterns that will generate complex bedforms and shoaling patterns. With abundant sediment on the ebb delta margin, bedforms of various scales and sizes are formed.

TABLE 2
PHYSICAL PARAMETERS FOR ST. MARYS INLET
(from Marino, 1986)

PARAMETER	DESCRIPTION	VALUE
V	Total volume of ebb tide delta	95×10^6 m^3
P	Spring tidal prism	154×10^6 m^3
A_c	Inlet cross-sectional area	12.4×10^3 m^2
W	Inlet width at throat	12.7×10^2 m
D	Inlet depth at throat	9.5 m
a_o	Ocean spring tidal amplitude	2.1 m
H_s	Significant wave height	0.55 m
T_w	Weighted mean wave period	6.0 sec

3. METHODOLOGY

The present study addresses the definition of time and space scales of bedforms and shoaling at Kings Bay entrance channel. Study techniques include surveys from surface vessels using high resolution down-looking and side-scan sonars, tied to an accurate navigation system. Repetitive surveys from the surface using the multi-frequency sonar provide snapshots of the bottom configuration and texture. Overlays of the bathymetry using sophisticated software provide information on the shoaling in the channel and on the ebb-tide delta. Repetitive side-scan sonar data provide quantitative information on bedform scales throughout various parts of the survey region. Changes associated with storm or fair weather waves are documented by these repetitive side-scan surveys.

3.1 SURVEY TECHNIQUES

Data were acquired along electronically guided tracks over the 14-mile length of the entrance channel and along cross lines to the channel in selected areas. Each survey involved 43 transects each 3000 feet long, 82 transects each 5300 feet long, 21 transects each 2600 feet long, and four transects each 67,924 feet long, for a total shiptrack of 169 miles. Ship's speed along the survey lines was about 5 miles/hour giving an uninterrupted running time of about 33.8 hours. A survey can normally be accomplished in four, 12-hour days. A list of survey equipment is given in

Table A1. All equipment was selected based on its demonstrated high accuracy and reliability (Aubrey *et al.,* 1988). The survey system has operated within specifications and expectations during the two-year period since purchase.

All surveys have been conducted from the 29-foot long charter boat *Sis*, which is powered by an inboard diesel. It has a cuddy cabin in the forward section of the vessel, and a soft canvas top aft of the cuddy cabin that has been modified for the project with a hard aft bulkhead. This modification was necessary to protect the equipment from inclement weather since some equipment was located just aft of the cuddy cabin. The crew of the *Sis* will work 12-hour days and on the weekends, thereby accomplishing the survey quickly. This reduction is critical in the winter when good weather and calm seas are rare. Surveying is limited to sea conditions of three feet significant wave height or less. Some of the disadvantages to using the *Sis* are inherent to all small boats. A larger boat offers more comfort for the crew thereby increasing productivity, gives better vessel stability (increasing survey accuracy and maximum sea state limits), and provides greater safety.

3.2 EQUIPMENT

A listing of all major equipment is provided in Appendix A. The equipment was selected and procured during Phase II of EMOGS. The fathometer used in the surveys is an Odom model DF-3200 (manufactured by Odom Hydrographic, Baton Rouge, Louisiana). The Odom model DF-3200 was chosen for its dual frequency capabilities, high precision, digital based construction, and its demonstrated high reliability. The system has operated flawlessly since it was purchased. The company has provided excellent product support for the unit when needed. The model DF-3200 has a 24/200 kHz transducer with a narrow beam (3 db at 19/9 degrees beamwidth respectively) propagation pattern. One frequency (user selectable) can be output serially with an optional upgrade from Odom to include both frequencies. The Odom DF-3200 has a resolution of 0.39 inches, but when error factors are considered (differences of water density, changes in transducer draft, calibration technique error, tidal correction errors, and sea state) an overall survey depth accuracy of one-to-two feet is estimated and verified by comparison of transects measured twice in succession.

The Klein side-scan sonar model 595 is a high resolution, dual frequency (100 and 500 kHz) side looking sonar that has digital and analog output. The system is used to typify the features over the surveyed bottom. The sidescan towfish is towed at 25-to-50 feet aft and center of the *Sis*, at a depth of about 10 feet. The system was chosen for its high resolution, its dual frequency capability, and the reputation of the manufacturer. Sand ripples, having a wavelength of 6 inches (amplitude of < 2"), can be observed from an altitude of 30 feet above the bottom using the Klein system. Although hard to quantify, the data from the Klein side-looking sonar give valuable and clear information about the shapes (acoustic reflectors) on the bottom. The Klein system was purchased with hands off tuning (HOT) to minimize the underway tuning required. A conventional side-scan system requires frequent tuning while being operated over a varying bottom. The HOT system has automatic gain control logic to keep the gain adjusted as a function of the returning signal strength.

The Del Norte model 547 trisponder navigation system has a specified accuracy of +/- 2 meters over a maximum transmission range of 80 kilometers. The system has worked well with some exceptions when the shore stations have been inoperative or poorly operative. The Del Norte system interrogates as many as four shore-located transponders at a maximum rate of 10 Hz and outputs distance measurements to the survey management computer. The survey management computer uses these data to calculate state plane coordinates, latitude, longitude, and project specific coordinates (cut, station and range).

The survey management system is an integrated navigation and data acquisition system (INDAS) purchased from Science Applications International Corporation (Newport R.I.). INDAS comprises a Hewlett Packard (HP) 9000 series model 220 processor with an HP 9153C disk drive (10 MB hard drive and a 800 KB, 3.5 inch floppy drive), necessary peripheral components (plotters, printers, monochrome monitor, and keyboard), and survey management software. Data are directed to the floppy drive during the survey. The survey management system provides accurate guidance to the helmsman, reliable data logging and clear annotation to peripherals.

4. RESULTS

All data were analyzed at Woods Hole. Tidal correction of bathymetry data was done with heights predicted by NOAA corrected to mean low water (MLW). Heights are predicted to the end of the north jetty (see Appendix A). Some cross channel lines were run twice (at different tidal stages) to check the accuracies of the tidal corrections to bathymetric data and the daily calibrations of the fathometer. Editing for horizontal and vertical wild points is accomplished automatically and checked manually. Plots and calculations are checked on hard copy before final plots and statistics are output. The output includes:

1. printing of depths (smoothsheets) versus position on state plane charts;
2. hard copies of contour and contour differences on state plane charts;
3. hard copy plots of bottom texture from side-scan data on state plane charts;
4. archival of all digital bathymetric and side-scan data, and
5. plots of statistical results (see probability results in this section).

4.1 BOTTOM TEXTURE

Dual frequency side-scan sonar data were recorded during all surveys. The side-scan data were analyzed at WHOI to compile bottom texture maps. The bottom texture description is made up of 15 categories (Figs. 2-9) some of which are presented from original records in figures C1 through C6. Ripples are defined as small sandwaves having a wavelength less than 1 foot. S1 sandwaves are 1-to-3 feet in wavelength. S2 sandwaves are 3-to-6 feet in wavelength and S3 sandwaves are greater than 12 feet in length. "Shoals" are defined as large bedforms that rise higher than 5 feet above the surrounding bottom. "Mottled" is a bottom giving a return that indicates poorly defined to almost nonexistent bedforms. "No bedform" is a bottom indicating no distinct shapes on the bottom. "Dredge marks" are identified by long scars along the channel. The original side-scan data were translated into the 15 categories and presented relative to state plane coordinates to form a texture map. The texture map was then digitized to form separate files on a Vax 8800 that were displayed using various plotting software.

Sandwaves can give an estimate of sediment type and dynamics in the nearshore zone. Between the jetties within the Saint Marys entrance channel, S1, S2, and S3 sandwaves were observed with more S3 waves than S1 or S2. Mottled bottom and no bedforms are less descriptive of sediment type and dynamics. Within the channel from station 21+400 outward to the start of the cut 2-N, the dominant bedform is mottled bottom. Eastward along cut 2-N, the dominant bedform is mottled with increasing amounts of no-bedform.

Within the channel the following summary statements about bottom texture apply:

1. From the eastern end of the channel to about station 220+00, mottled and "no-bedforms" are the dominant bottom texture.
2. From station 220+00 to station 72+00 the bottom texture is dominated by S3 with some S2 sandwaves.

Outside the jetties north and south of the channel there are bedforms of various types. All 15 bedform types are found in the west portion of the survey area (Fig. 1 and Table 1) inside the jetties (Reach 5). Outside the jetties north and south of the channel out to station 270+00 are areas where many changes occur. Areas that seems to have stable bottom texture are:

1. Seaward of the 214+00 station to the end of the ebb tide delta at station 320+00 "mottled" bottom texture dominates in the channel, north to range 4500, and south as far as range -800.
2. At the seaward end of the north jetty "no-bedforms" dominate.
3. A wedge of S1 type sandwaves occurs along the large shoal area that runs toward the channel from the north at station 160+00, then extends along the north side of the channel from station 176+00 to 190+00.
3. The area south of the channel (range -800 to 600) from station 180+00 to station 270+00 is dominated by S1 and S3 sandwave types. This area has changing bottom texture but the S1 and S3 sandwave types are the most common.
4. In the area north of the channel from stations 160+00 to 230+00, all 15 bedform types have been found and except for the S1 dominated area along the major shoal discussed above (station 160+00 to 190+00), no dominance of any type is observed in the area. The lack of bottom texture stability in this area indicates that the area has active sediment transport. Observing that the net sediment transport is from north to south (e.g., Marino, 1986) leads to the conclusion that this area should contribute most toward sedimentation. This conclusion is supported by maintenance dredging records that indicate <u>all</u> maintenance dredging since 1988 has been concentrated in this area.
5. South of the channel from stations 72+00 to 110+00 is a wedge of S3 sandwaves.
6. North of the channel from stations 120+00 to 150+00 are 4 shoal ridges that have migrating slowly to the south during the 3 years of observations.
7. Another stable shoal is found south of station 72+00.

Other areas from station 72+00 out to the end of the jetties are unstable with all 15 bottom texture types found during various surveys.

4.2 SEDIMENTATION

4.2a BATHYMETRIC MAPS

During phase III in FY1990, two surveys were accomplished (Table 3). Bathymetric smoothsheets from these surveys produced a time series of data that indicates a fluctuation in size and position of the major shoals, suggesting migration. Although major shoals north and south of the channel move slowly, there is strong evidence that smaller bedforms are constantly changing and that the channel is a strong sink for sediment. The areas of concern for channel shoaling are near the mouth of the jetties, and on the ebb tide delta outside the jetties in Reach 3 (Table 1).

Since the inception of the sediment study (1987) bathymetry data have indicated there are large shoals which maintain their general location, but vary in size, shape, and position. Of these shoals most dramatic is the shoal north of the channel from station 160+00 to 190+00. Predominate forcing from waves and tide cause sediments to form distinct forms. These distinct sediment forms indicate locations of most pronounced sediment transport. The sections of channel adjacent the shoal at stations 160+00 to 190+00 and another large shoal area located at stations 240+00 to 260+00 north of the channel are ones that have been included during all maintenance dredging operations since the acceptance of the 46-foot channel. From the bathymetry data and dredging history the conclusion is made that the channel area from station 160+00 to 260+00 is the primary shoaling location or "hotspot".

Accretion of 2.5 feet average depth occurred in Reach 3 (Tables D5 and D6) between the September and the October surveys (during which time Hurricane Hugo passed); this was the largest accretion in channel depth on a reach-by-reach basis during 1989. One way to monitor this hotspot is to install in-situ sand level monitors in the area. Other methods have been proposed and/or are in effect currently (see EMOGS operations plan).

4.2b QUANTITATIVE COMPARISON OF MAPS

The bathymetry data have been kept in uniform format throughout the survey where possible, to make intercomparison easier. The accuracy of the horizontal navigation is about a meter. The depth error can be 1-to-2 feet due to sea state and tide prediction errors. A sediment model was based on these data. This section describes the methods for analyzing the data to serve as input to the model development.

The data were divided into several subsets to investigate shoaling patterns. One way to perform the analysis was to represent the bathymetry by a gridded matrix with depths assigned to each cell. This facilitated bathymetry change analysis since each survey was standardized. Another way to study changes was to plot profiles of one survey with another. This allowed an easy interpretation of lateral bedform movement. Once the differences between surveys was sufficiently understood as to their causes, and quantified, a coupling could be accomplished between sediment patterns and environmental controls such as waves, wind and tidal flows. The process of understanding sedimentation followed this basic outline:

- Fill the matrices from each survey. This included a matrix of the settling basin, the channel to the dogleg, and the channel from the dogleg to the end of the survey.
- Isolate survey lines of processed data which passed through pre-chosen stations and send them to a PC for analysis.
- Plot the settling basin matrix differences in a two-dimensional plane, then in a three-dimensional view. These would show shoaling or accretion patterns between two surveys.
- Quantify the differences in the settling basin matrices as a function of distance along the channel axis.
- Separate the settling basin matrix into three zones - the channel, the northern shelf, and the southern shelf.
- Quantify depth differences in each of the three settling basin zones. This would isolate the susceptibility of each zone to changes assuming they are decoupled by the presence of the channel.

- Superimpose the two-dimensional profiles from each survey to investigate the manner in which sediment is transported into the channel - from bedform migration or bed load.
- Couple the quantified results with statistical representations of the wavefield between the surveys.

TABLE 3
BATHYMETRIC CRUISE SCHEDULE

DATE	EXTENT - TYPE of WORK	DREDGED SINCE LAST SURVEY?
September 1987	Partial (50%)	NA
October 1987	Partial (50%)	6/87-2/88 Maintenance, 321,000 cy New work, 906,000 cy 9/87-5/88 New work, 2,133,000 cy
February 1988	Complete survey	
May 1988	Complete survey	
July 1988	Complete survey	5/88-12/89 New work, 5,456,000 cy
January 1989	Complete survey	10-12/88 Maintenance, 720,000 cy
March 1989	Complete survey	No dredging
8-13 June 1989	Complete survey	6/89 Maintenance, 152,000 cy
10-16 September 1989	Complete survey	No dredging
9/28-10/3, 1989	Located sunken buoy #17	No dredging
4-16 October 1989	Complete survey	No dredging
3-6 January 1990	Complete survey	11/89 Maintenance, 754,100 cy
June 1990	Complete survey	No dredging

Figure 10a shows the matrix zones in the settling basin for reaches 3, 4, and 5. Since the survey was conducted along the channel beyond the delta, the matrices developed for reaches 1 and 2 simply run inside the channel slope along the axis. Figure 10b shows the transects selected in the settling basin to pass through "hotspots" in order to study the profiles from successive surveys.

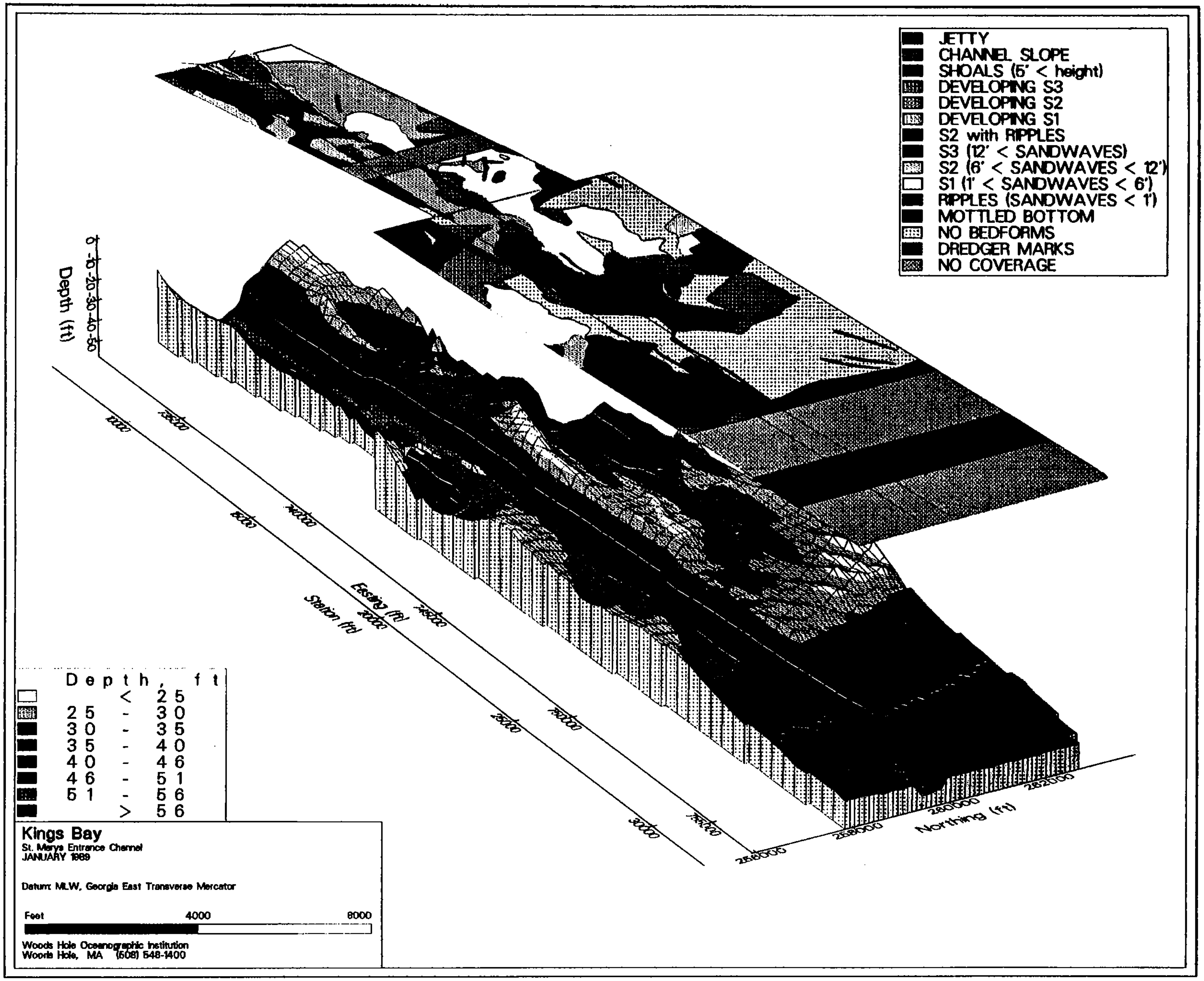


Figure 2. Bathymetry and texture overlay for January 1989

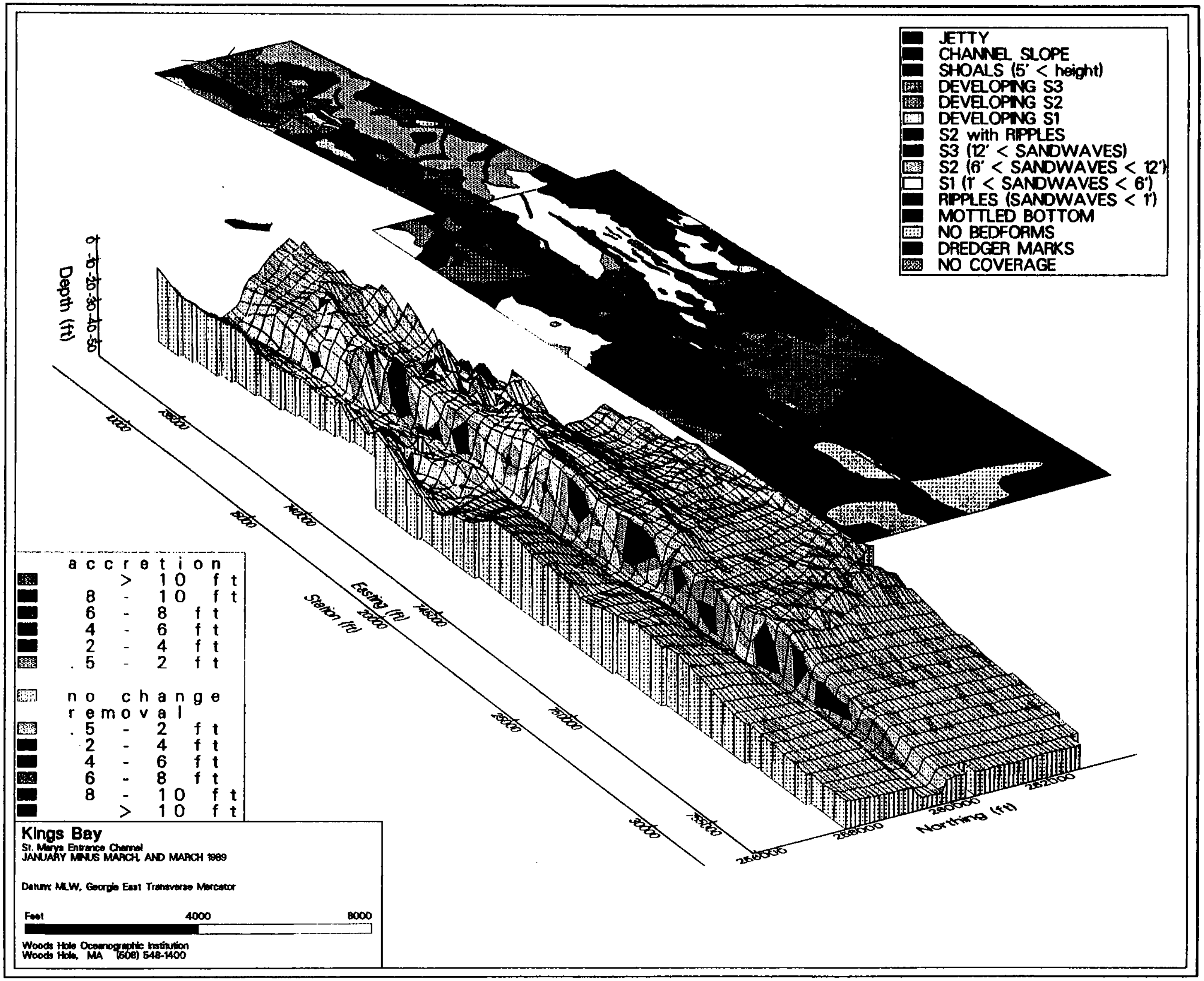


Figure 3. Bathymetry, volume difference, and texture overlay for March 1989

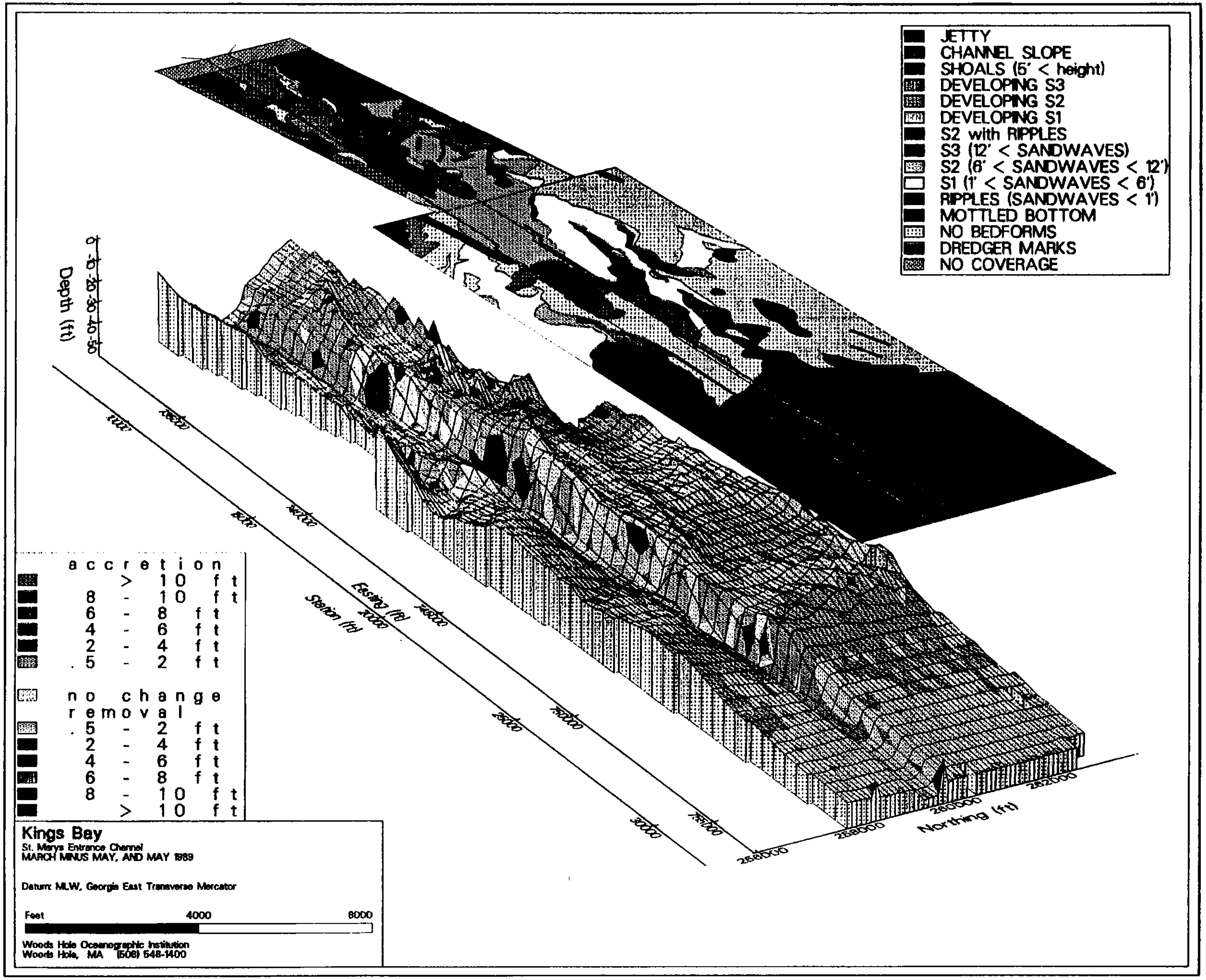


Figure 4. Bathymetry, volume difference, and texture overlay for May 1989

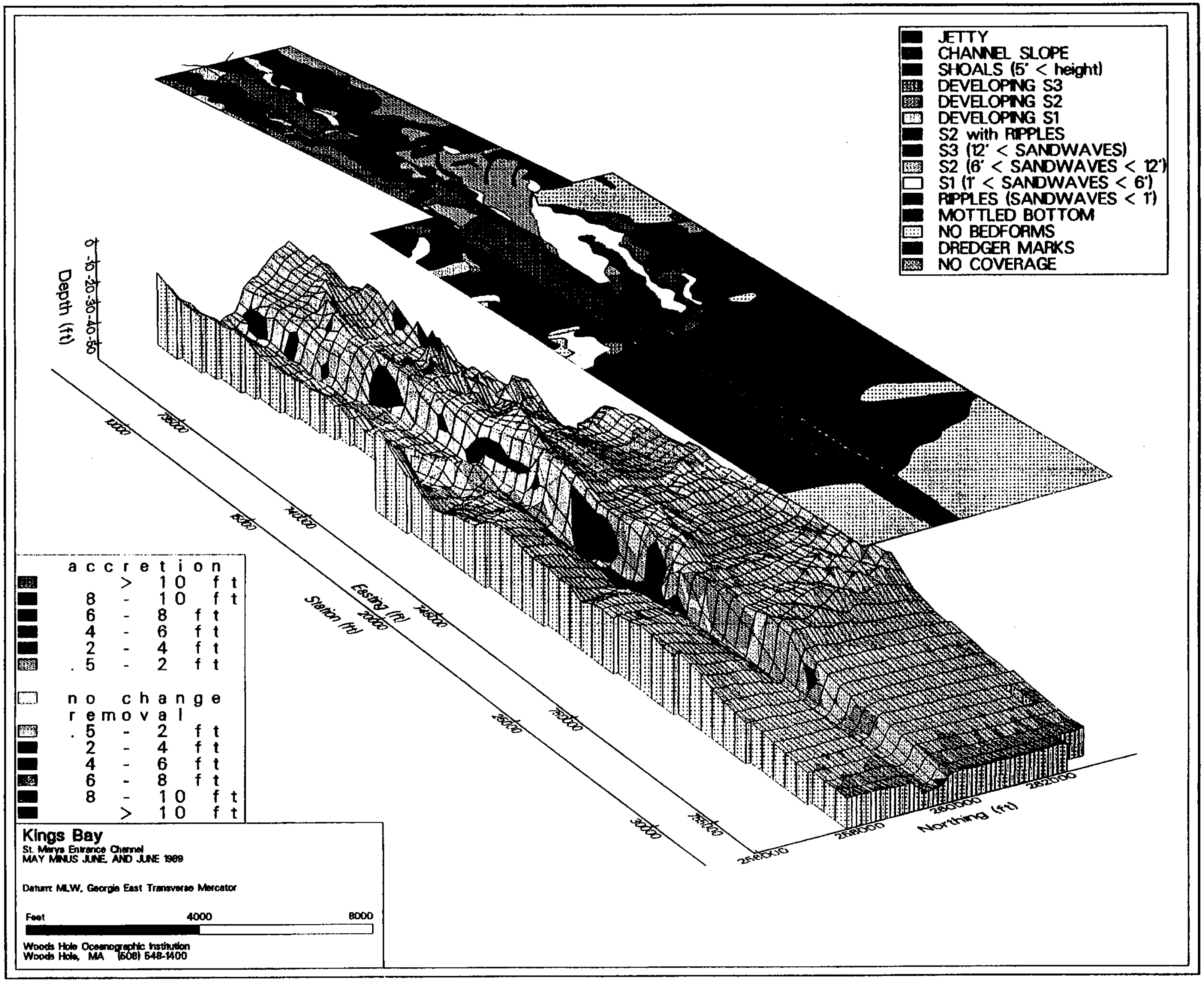


Figure 5. Bathymetry, volume difference, and texture overlay for June 1989

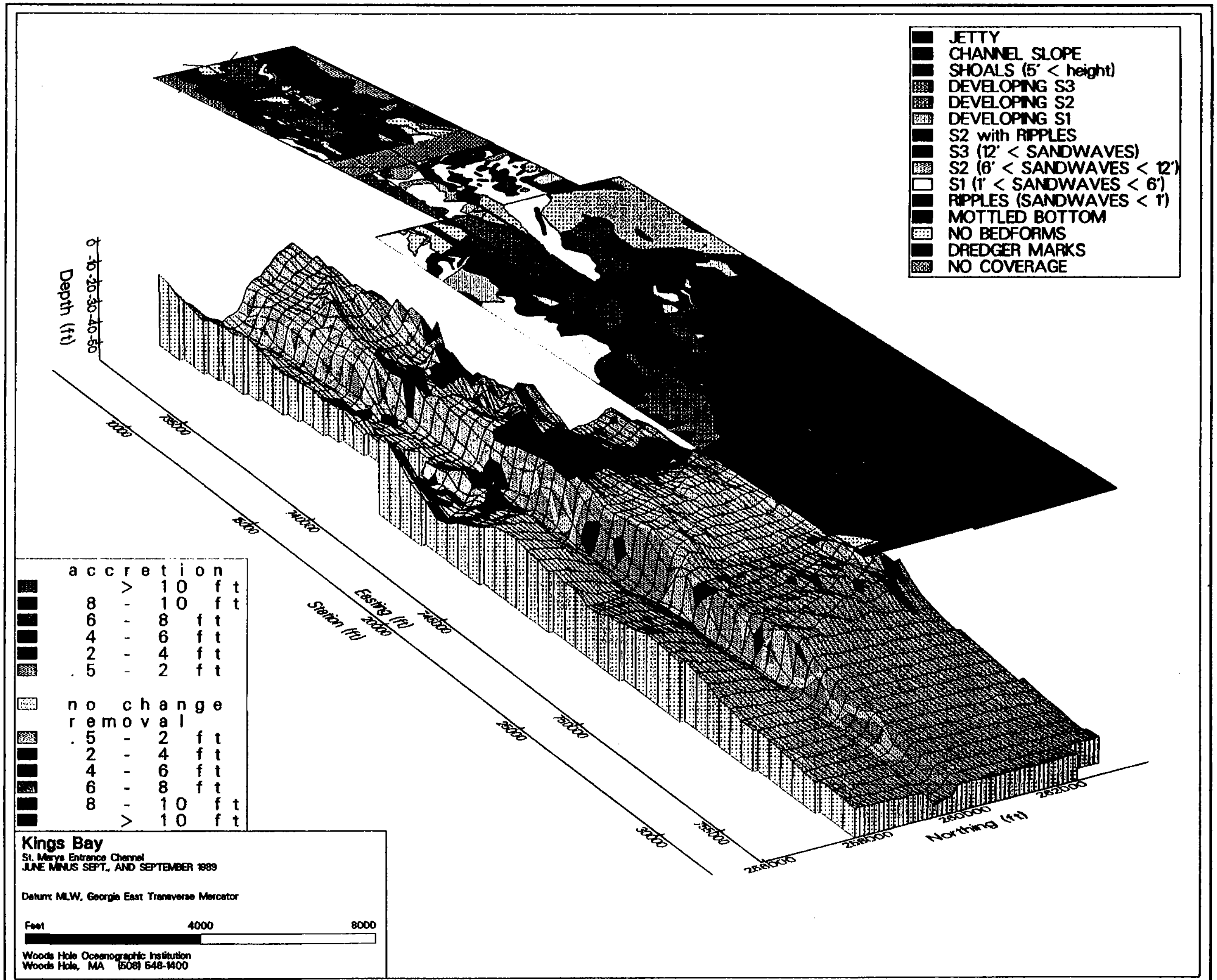


Figure 6. Bathymetry, volume difference, and texture overlay for September 1989

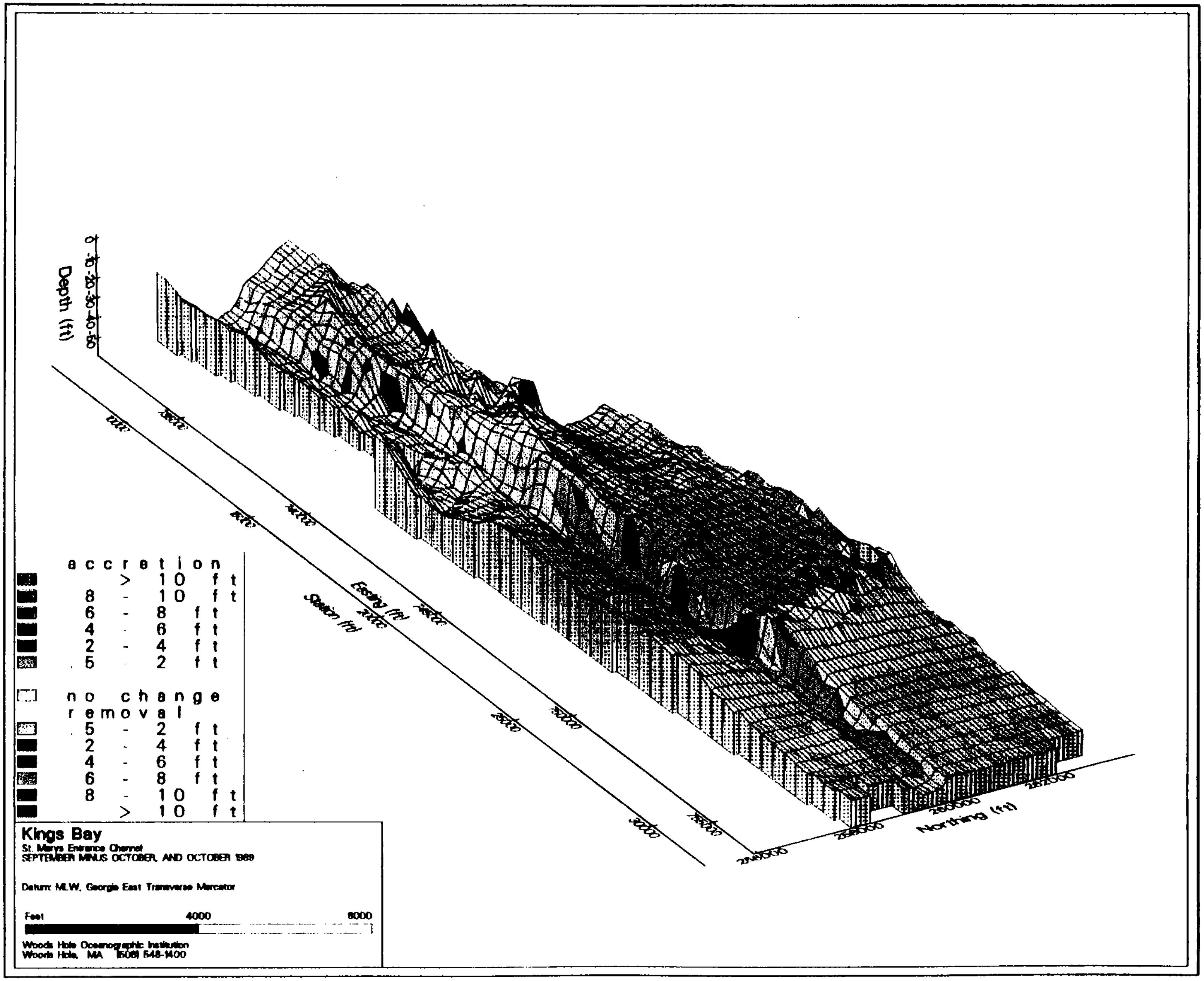


Figure 7. Bathymetry and volume difference for October 1989

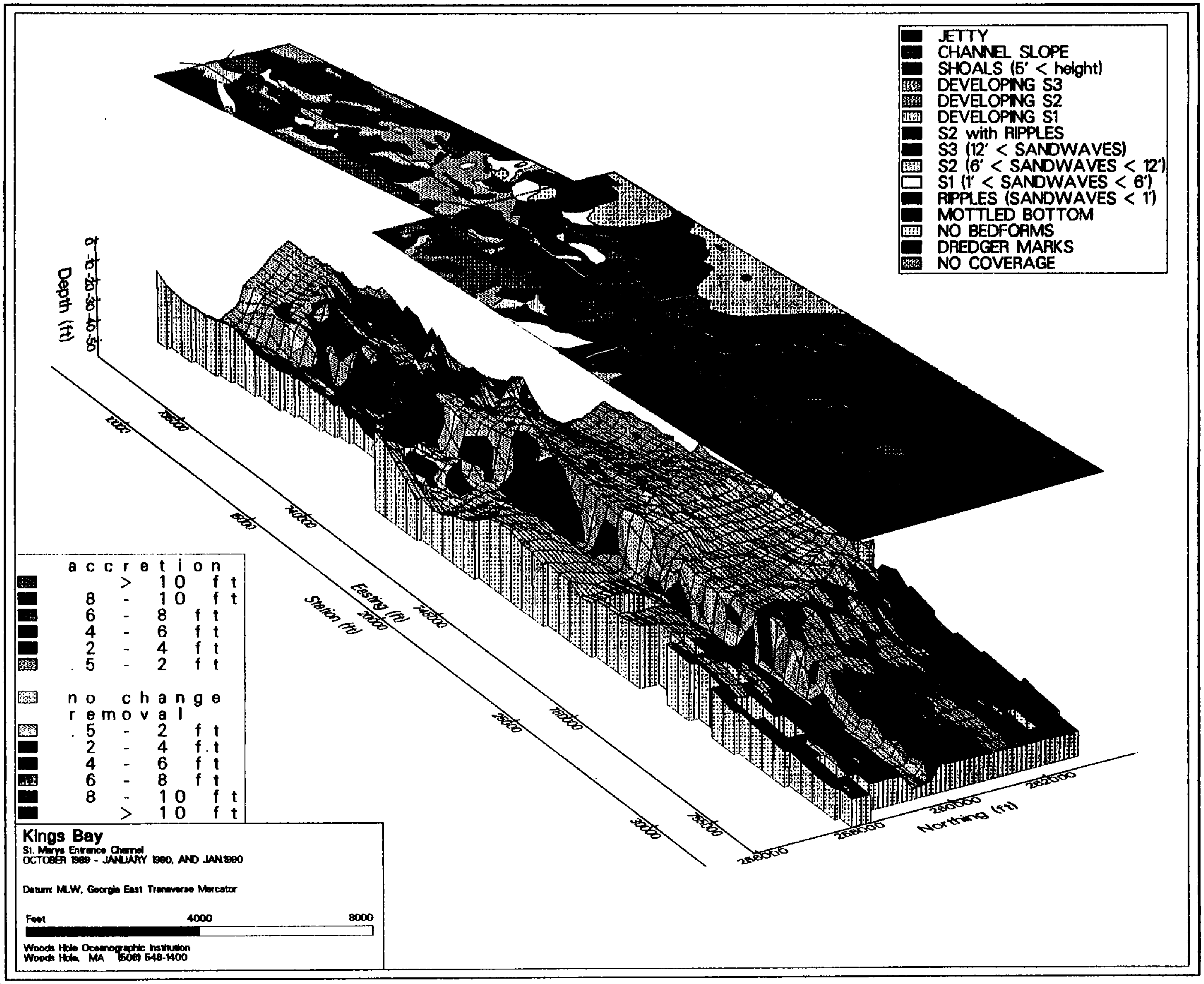


Figure 8. Bathymetry, volume difference, and texture overlay for January 1990

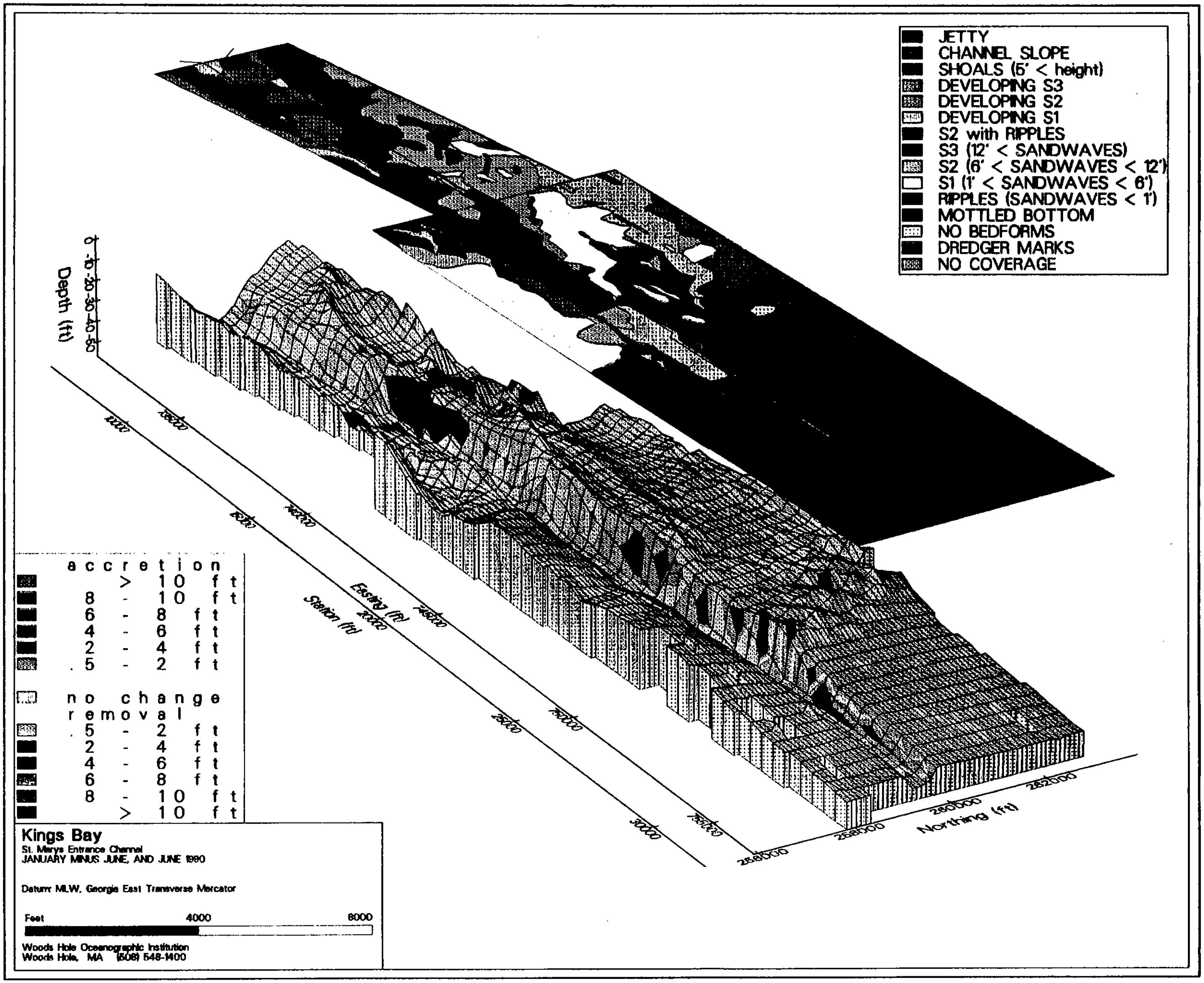


Figure 9. Bathymetry, volume difference, and texture overlay for June 1990

TABLE 4
AVERAGES CALCULATED FROM CHANNEL BATHYMETRY DATA
FOR THE SURVEYS

REACH	AVERAGE DEPTH (ft - MLW datum)	MINIMUM DEPTH (ft - MLW datum)	STANDARD DEV. (ft)
1	51.9	47.7	1.6
2	51.5	45.3	1.7
3	50.2	41.0	1.9
4	51.2	36.8	1.9
5	50.1	32.6	2.8

Wave data were available outside the St. Marys entrance channel from Wavescan buoys deployed by David Taylor Research Center and from bottom-mounted gauges installed and maintained by the University of Florida. The sites for these instruments are shown in figure 10a as "DT" for the wavescan buoys and "UF" for the Florida gauges. Wave summaries in the form of significant wave height, peak period, and wave direction have been provided by these organizations for use in this report. Figure 11 shows significant wave height, peak period and direction throughout the study. Some gaps occur where data were unavailable from the instruments. The data from the two sources were integrated, however, to minimize the gaps. Data compare well except for a two-month period in the winter of 1989 where wave direction is shown out of the west. This is suspect and may be due to an unaccounted-for compass shift. Clearly the two-year period was relatively calm with H_S of 3-4 feet almost continuously. This makes sedimentation predictions from possible storm events difficult, requiring extrapolation or modeling.

Figure 12b is a sample of the net cross-channel change in depth between two surveys as a function of station. This is helpful in isolating areas of high sedimentation. The dashed lines refer to the standard deviation in the lumped cross-survey depth estimate for each x-position. Figure 12a is a profile plot of a preselected "hot spot" between two surveys. This location shows movement of the larger bedforms in Kings Bay, and by overlaying the profile plots from each survey, a "movie" is formed depicting the mechanism of sediment movement, and the time-scales of bedform movement.

The dredging activity is limited to the channel, so this removal must be accounted for in the final volume change numbers. The May 1989 dredging occurred between the May and June surveys, removing 152,000 cubic yards of material between stations 218+00 and 329+00. Using a percent based on area percentage dredged, 18,200 c.y. was removed from Reach 2, 109,400 c.y. was removed from Reach 3, and 24,400 c.y. was removed from Reach 4. Another dredging activity in November 1989 removed 754,100 cubic yards of sediment from Reaches 2, 3, and 4. The bounding stations affected by the activity are not explicit, so the previous percentages were used to obtain a removal of 90,500 in Reach 2, 542,900 in Reach 3, and 120,600 in Reach 4. Tables 5 and 6 are a compilation of volume changes between surveys for the different Reaches accounting for the dredge material removed. A shoaling of depths appears in the Tables as a positive, bold value, while a net removal between surveys is a negative.

By using the surface area of each of the matrices , an "activity parameter" is defined as

$$A_p = \frac{\sum |V_1 - V_2|}{A_r} \tag{1}$$

where V_1 and V_2 are the volumes differences of successive surveys in each matrix region and A_r is the surface area of the region. Figure 13 shows the activity parameters for each of the reaches and each of the zones in the settling basin. It is important to note that local changes within an area may offset, giving a deceptive net result, but the purpose of the activity parameter is to evaluate the level of change. Although the units of the A_p is a length, it is not correct to apply this as a uniform depth change over the region. It is correct, obviously, to multiple this by A_r to get the total gross volume change within a region, hence the level of "activity".

TABLE 5
NET VOLUME CHANGE IN REACHES 3-5 (cubic yards x 10^6)

SURVEY	REACH 5			REACH 4			REACH 3		
INTERVAL	NORTH	CHANNEL	SOUTH	NORTH	CHANNEL	SOUTH	NORTH	CHANNEL	SOUTH
January-March '89	**0.49**	**0.34**	**0.67**	-0.75	-0.07	-0.71	-0.28	**0.34**	-0.48
March-May '89	**1.97**	**0.60**	**0.68**	-0.88	-0.12	-0.35	**0.62**	**0.13**	**0.48**
May-June '89	-0.70	-0.40	-0.27	-0.15	-0.58	-0.09	-0.17	-0.30	-0.32
June-Sept. '89	**0.77**	**0.45**	**0.31**	-0.28	**0.40**	-0.05	**0.47**	**0.39**	**0.52**
Sept.-Oct. '89	-2.00	-0.63	-0.96	**0.91**	**0.21**	**0.42**	-1.50	**0.30**	-0.70
Oct. '89-Jan. '90	**0.68**	**0.42**	**0.57**	**0.74**	**0.45**	**0.21**	**3.43**	-0.08	**1.37**
Jan. '90-June '90	-1.28	-0.36	-0.50	-0.99	-0.14	-0.45	-2.53	**0.30**	-1.07

TABLE 6
NET VOLUME CHANGE FOR REACHES 1 and 2 (cubic yards x 10^{6})

SURVEY INTERVAL	REACH 2	REACH 1
January - March 1989	-0.47	-0.29
March - May 1989	**0.20**	**0.11**
May - June 1989	-0.02	-0.02
June - September 1989	**0.31**	-0.24
September - October 1989	**0.71**	-0.25
October '89 - January '90	-0.08	**0.15**
January - June 1990	**0.32**	**0.09**

The following paragraphs summarize the wave inputs and resulting volume changes.

Survey Interval 1 (January - March 1989)

The wave conditions during this period were more vigorous than was the norm over the project. Wave directions were out of the southeast predominantly, with 3 to 4 foot significant wave heights, however a storm delivered 13 foot waves into the area over January 21-24. The peak period during this event was 7-12 seconds, and the wave heading was questionable due to the data from the Florida wave gauge. At sections B and D (Reach 5) (Fig. 10b), the bedforms north of the channel migrated north 100 feet and reduced in amplitude by up to 5 feet. This represents a large amount of sediment which shifted. Table 5 shows a net material shoaling on the north side of 490,000 c.y.. From the composite (Fig. 3), Reaches 3, 4, and 5 experience accretion on the northern edge of the channel, while the channel shoals 1 foot in Reach 3. The A_p is comparable for Reach 5 for all three regions, with slightly more activity in Reach 4 on the south side. The channel is the most active in Reach 3, and Reaches 1 and 2 show decreasing levels of activity.

Survey Interval 2 (March - May 1989)

The wave conditions were mild throughout the interval, with predominant H_s of 3 feet out of the southeast and a maximum on March 23-24 with 6 foot wave heights and periods of 7 seconds. Plotting the hotspot profiles, shoaling occurred in the sediment basin at section B (Fig. 12a). There was 0.5-to-1 foot of shoaling in the channel in Reaches 3 and 4. The composite (Fig. 4) shows a net increase in sand level in Reach 5 throughout. Accretion of up to four feet occurred at section F, where a large shoal lies adjacent the channel to the north. The A_p is very similar for all three regions in Reaches 3 through 5, with little activity in Reaches 1 and 2.

Survey Interval 3 (May - June 1989)

Wave conditions were mild, with 3 foot significant wave heights out of the east and southeast with 7-8 seconds modal periods. The largest event produced 8 foot waves on May 29 out of the northeast with a period of 9 seconds. Profile plots across the survey show the effects of the dredging activity on June 1-15, where 152,000 c.y. were removed. The channel depths increased in Reaches 3 and 4 by 1-to-5 feet. The composite (Fig. 5) shows this dredge removal in the channel, and removal on the channel sides. The activity parameter reflects the changes brought about in Reaches 3 and 4 by dredge operations.

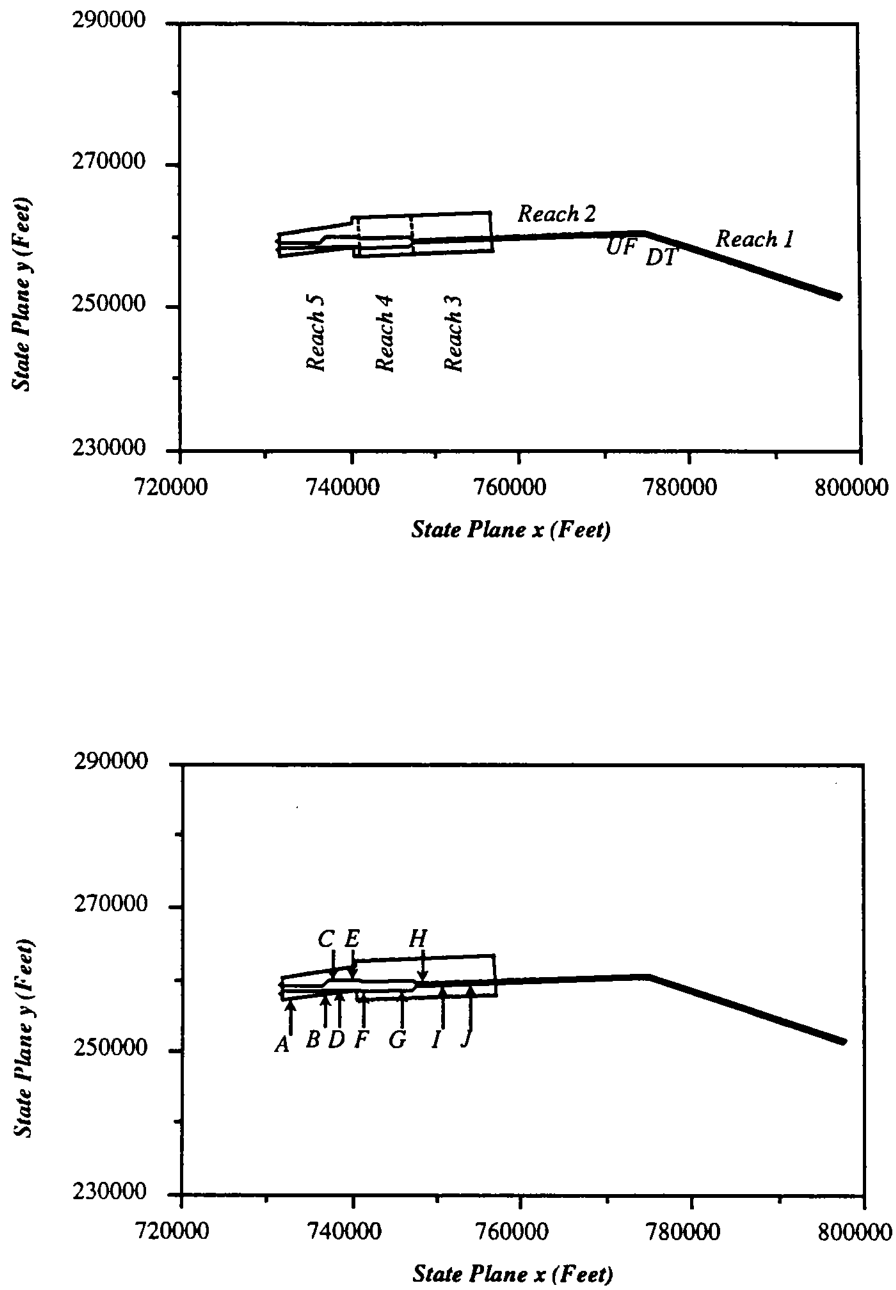


Figure 10. a.) Matrix zones for bathymetry analysis in settling basin.
b.) Transects in settling basin identifying "hotspots" for profile study.

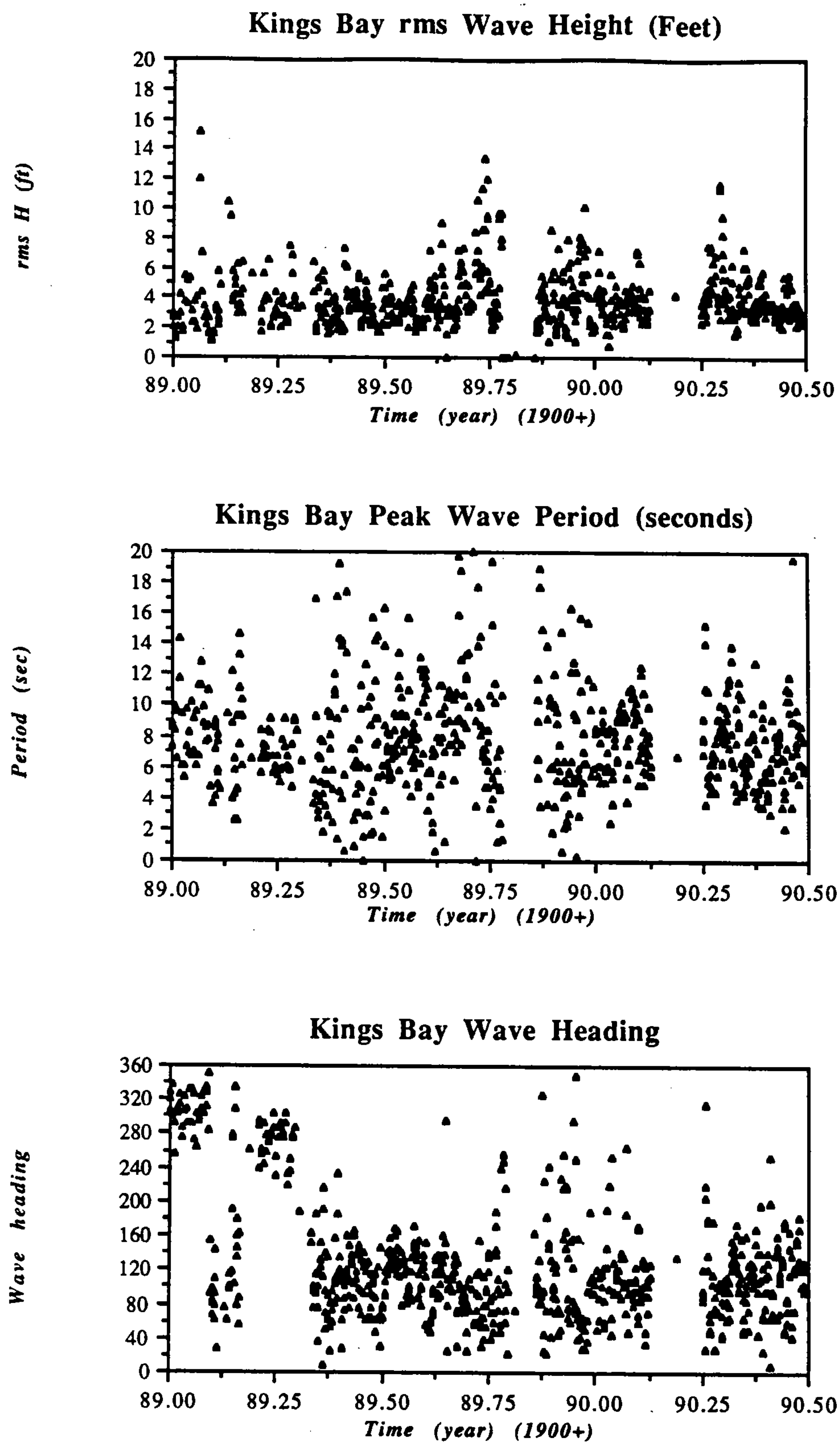
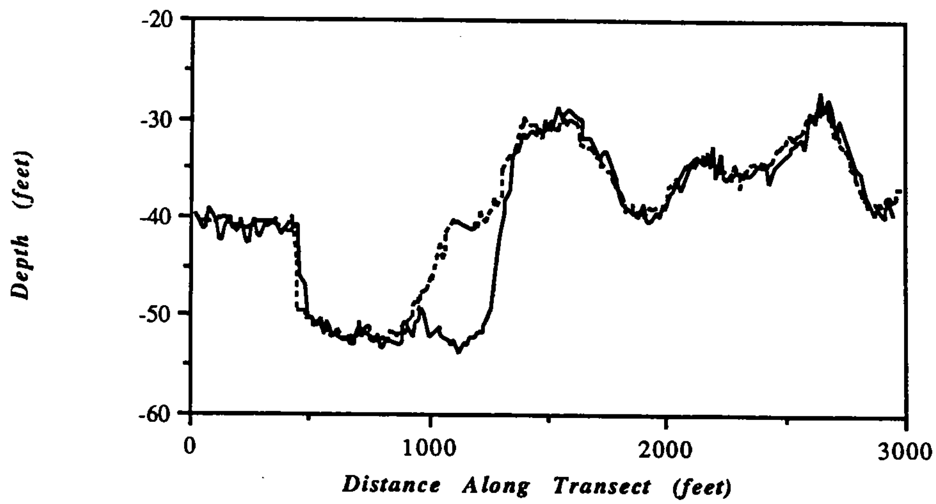


Figure 11. Wave conditions during the survey period.



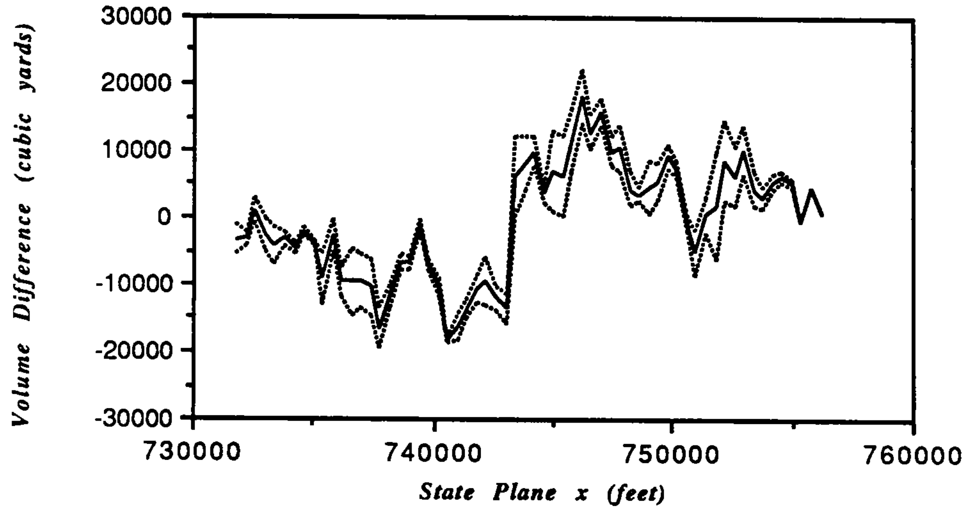


Figure 12. a.) Profile evolution between March - May 1989 at site B. (see Fig. 10b) b.) Net volume change along channel between September - October 1989. (Dashed line is standard deviation.)

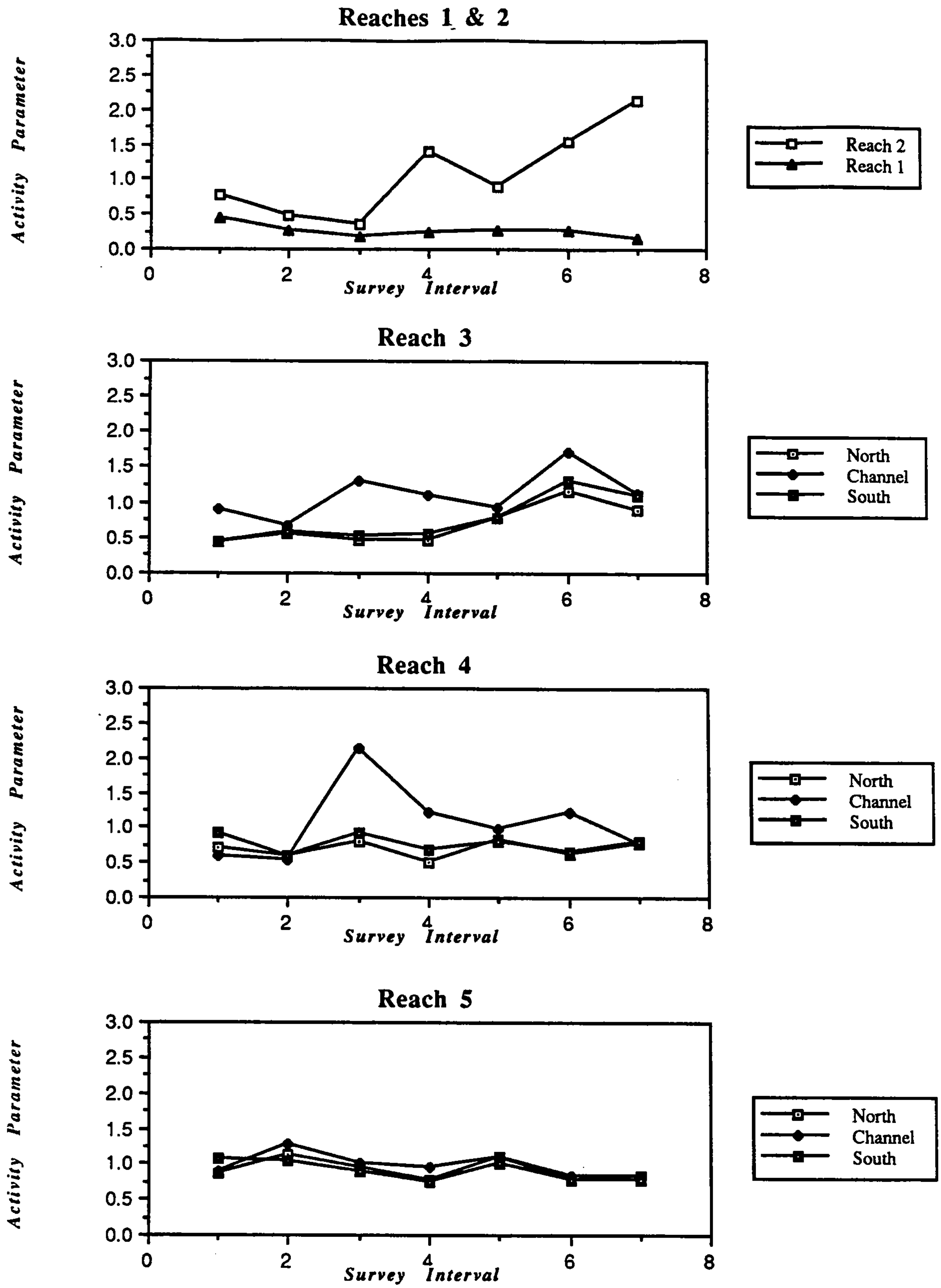


Figure 13. Activity parameters for each of the surveys.

Survey Interval 4 (June - September 1989)

Wave conditions were slightly more vigorous, with 3-to-5 foot significant wave heights out of the east and southeast. The largest event took place on August 21-22 having 7 foot waves out of the southeast with a peak period of 10 seconds. The channel recovered from the June dredging by shoaling as much as 4 feet in the affected area in Reach 4. Also, the region which experienced shoaling between May and June (station 155+00) went through an erosional period during the summer months. The A_p in the channel in Reaches 3 and 4 remains above that for the north and south sides. This could be due to channel recovery after the dredge operations. Also, the parameter in Reach 2 jumps to a high level. This shows that Reach 2 can still be an active sediment transport zone. The composite (Fig. 6) shows erosion north of the channel in Reach 5, and accretion of material on the north side of the channel in Reach 4.

Survey Interval 5 (September - October 1989)

The wave climate included typical 5-to-6 foot significant wave heights and Hurricane Hugo which had 10 foot waves out of the east with a modal period 8-15 seconds. The profiles show slumping of the northern channel edge at section F in Reach 4 (Fig. 14). The channel in Reach 3 experienced 1-to-3 feet of accretion. The composite (Fig. 7) shows 0.5-to-4 feet of accretion on the north and south sides in Reach 4, as well as 0.5-to-4 feet of accretion in the channel in Reach 3.

Survey Interval 6 (October 1989 - January 1990)

The wave climate calmed to the usual 3-to-4 foot H_s out of the east, with the largest wave at 7 feet on December 22-24 out of the northeast with 8 second peak periods. Material was removed from Reaches 2, 3, and 4 by dredging in November, 1989. This is reflected on the composite (Fig. 8). The A_p also reflects these operations in the channel. The composite shows accretion in Reaches 4 and 5 in all three regions, and accretion north and south of the channel in Reach 3.

Survey Interval 7 (January - June 1990)

The wave climate was calm, with 3-to-4 foot significant wave heights. The largest waves were on April 19-20 at 9-to-10 feet out of the northeast, with a 7 second peak period. The channel in Reach 3 accreted as it recovered from the dredging. The northern and southern sides in Reaches 3 and 4 eroded material, appearing to approach a level of equilibrium. The activity parameter in Reach 2 was very high, possibly a data problem. The composite (Fig. 9) shows erosion north of the channel in Reaches 3, 4, and 5.

From the surveys, several important characteristics have been discovered about St. Marys entrance channel. One of the questions when the program began was whether the large shoals north of the channel move south. During the study interval, the shoals between the jetties moved, but not in a consistent manner. The bedforms had periods of movement to the south, then to the north, oscillating about a fairly central point. The heights of the bedforms also changed from survey to survey. After periods of high wave energy, the amplitudes showed signs of diminishing, growing during quiescent periods. Thus, significant quantities of sediment moved on a frequent basis, even during periods of relatively low storm activity. The mode of transport was shoal migration with active bedload transport on the shoals contributing to sedimentation.

The channel requires maintenance dredging and emergency service from time-to-time. The difference plots between surveys show accretion along the channel sides, especially at station 240+00 where a large bedform rests on the northern edge of the channel. By using the profile evolution, there is evident sloughing by the channel edges after either reaching a critical steepness or after an energetic storm. Following Hurricane Hugo in September, 1989, the channel sides in Reach 3 showed a one-to-three foot sand level change, with a concurrent accretion in the channel.

Because of the weakness of storms and relatively infrequent surveying, it is difficult to draw a quantitative connection between waves and rates of sediment accretion. There are locations in the settling basin which always are in need of maintenance dredging due to geometry and divergence of tidal flow. The net volume differences in each of the matrix regions (Tables 5 and 6) help isolate areas of activity through the activity parameter. From Figure 13, in all of the settling basin zones the channel matrix is consistently the most affected between surveys. The north and south sides of the channel are both less active than the channel, having similar responses. The low activity in Reach 1 during the study period suggests a stable environment. Reach 2 shows a capacity to experience significant sediment movement.

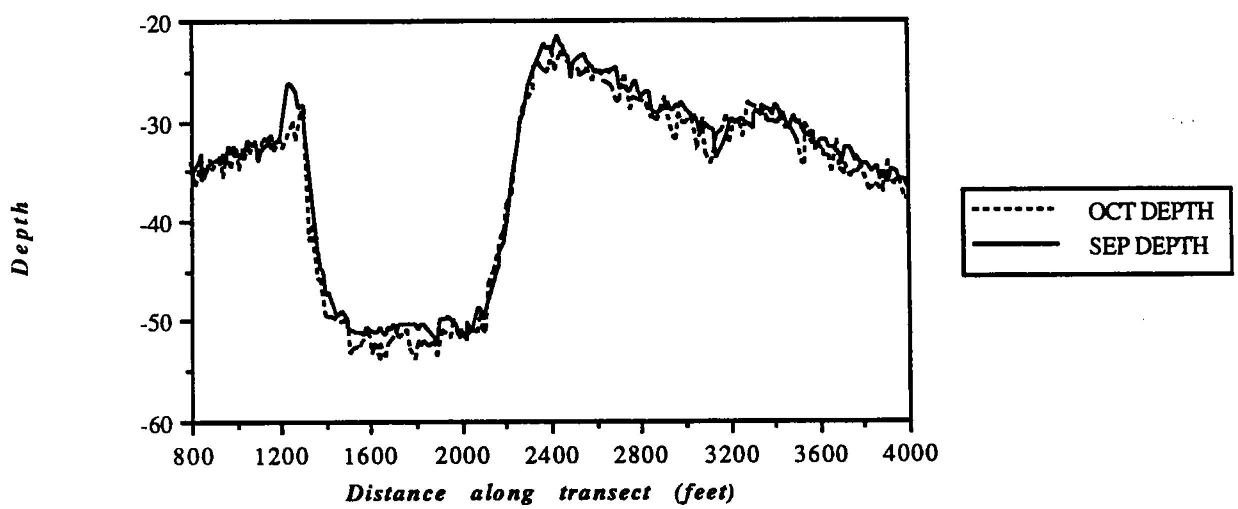


Figure 14. Section F (see Fig. 10b) showing slumping of channel edges after Hurricane Hugo

4.2.c SHOALING TENDENCIES

A probabilistic description of the survey data was made that considered those data points inside the channel margin boundaries, including the channel slopes. We performed statistical tests on these data that would be useful to EMOGS in describing the bathymetric changes of the channel.

An analysis program has been transferred to the Army Corps of Engineers in Jacksonville, Florida, to perform the following tasks:

1. filter bad data
2. application of tide correction
3. separation of depth data lying within the channel slope margins
4. separation of channel depth samples into the five defined reaches, from inside the jetty to beyond the dogleg (see Figure 1)
5. calculation of sample mean, standard deviation, skewness and kurtosis for each reach sample
6. calculation of sample 97.5% confidence intervals of skewness and kurtosis for a normal distribution
7. definition of the 99th percentile depth in each reach sample, that is, the depth which 99 percent of the sample exceeds
8. listing and location of depths shallower than the 99th percentile depth.
9. tabulation of frequency distributions for depths from 0 to 100 feet
10. tabulation of depth and location for samples occurring within 50 feet of stations 122+00, 180+00, 234+00, 238+00, 282+00, and 284+00

The data were filtered by eliminating depths less than 25 feet and greater than 100 feet. The second task was to apply an appropriate tide correction. The ACE in Jacksonville uses telemetered data from onsite installations which inject the tide correction directly into the data acquisitioning, therefore providing a correction for each point. The tide values are predicted from real time tide observations made just south of the south jetty at about station 130+00. The popular opinion is that the predictions have a maximum error of $\pm$ 0.3 feet. Woods Hole uses hourly predicted data from National Ocean Service's extrapolations from tide stations to the end of the north jetty at St. Marys entrance channel. These data are external to the depth data, and must be inserted during the data analysis procedure. In the present algorithm, the day, hour and minute for each point are read and the correction is interpolated using a straight line approximation of the hourly tide record.

With the corners of the channel template provided, each point's location is then read to determine whether the data fall within the channel margins. Separation into the five reaches finally yields five sets of depth data for further processing. Once the data samples have been defined for each reach, the mean and standard deviations are calculated:

$$\bar{z} = \frac{1}{N}\sum_{1}^{N} z \qquad (2)$$

$$\sigma^2_z = \frac{1}{N-1}\sum_{N}^{1}(z - \bar{z})^2 \qquad (3)$$

where N is total number of samples. The skewness determines the bias of the sample about the mean, and was represented by a skewness coefficient defined as,

$$\gamma_z = \frac{1}{\sigma^3 N} \sum_{1}^{N} (z - \bar{z})^3 \tag{4}$$

The kurtosis describes the shape of the frequency diagram in terms of its distribution about the mean value. If the sample is highly kurtotic, the frequency diagram is sharply peaked about the mean, with a low, flat slope. If the sample is slightly kurtotic, the depths are distributed more equally over the range of values. Kurtosis was determined by a kurtosis coefficient:

$$\beta = \frac{1}{\sigma^4 N} \sum_{1}^{N} (z - \bar{z})^4 - 3 \tag{5}$$

It was of interest to compare the samples to a normal sample. The normal distribution sample would have confidence intervals on skewness and kurtosis, to evaluate normality. For a 2.5% confidence the skewness and kurtosis confidence intervals are, respectively,

$$\text{skew}_{c.i.} = \sqrt{\frac{6}{N}} \tag{6}$$

$$\text{kurtosis}_{c.i.} = \sqrt{\frac{24}{N}} \tag{7}$$

One important aspect of the EMOGS program is to determine a channel "controlling depth". This depth has been defined as the 99th percentile depth, or the depth that 99% of the other depths in the channel exceed. This is calculated in the model as a frequency distribution for each reach; the area under this function is summed until the area equals or exceeds 1% of the total area. The depth corresponding to this 1% area is defined as the controlling depth. As part of the program, this controlling depth is output in a summary of the statistical characteristics of each reach sample. In addition, depths which fall short of this depth are listed along with their locations. The frequency distribution for depth from 0 to 100 feet are recorded to a separate file.

Finally, the program outputs depth and location along six selected stations, 122+00, 180+00, 234+00, 238+00, 282+00, and 284+00. These were chosen as representative stations in the survey, since they pass through historically determined accretion zones. These stations are all on Cut 1-N, where sediment accretion has been documented. The surveys east of the dogleg show that these depths have been stable during our analysis.

The results from the statistical algorithm are presented for each of the six surveys from 1989. Survey results consist of a summary of the pertinent statistical quantities on a reach-by-reach basis in Appendix D, frequency tables of depth for each reach in Appendix E, a plot of the frequency distributions for each reach (figures 15-22), the 99 percent depths with locations of depths shallower in Appendix F, and plots of range versus depth at selected stations for each survey in Appendix G. A short synopsis is given for each month's results below.

January 1989

For this survey, the average depths were consistently about 51 feet (Appendix D: Table D1), with the lowest average in Reach 3. Channel depths spread about this mean by roughly 1.5

feet, with the greatest spread in Reach 5. During the course of the investigations at St. Marys Inlet, we have discovered active sediment movement in Reach 5 due to the strong tidal flows. This trend remained through the 1989 survey season. From Table D1, it is seen that the sample distributions are confirmed non-normal in skewness and kurtosis. A skewed distribution means the depths are biased about the mean to shallower or deeper depths, depending on the sign of the coefficient. A kurtotic distribution has depths either gathered about the mean in a peak, or spread fairly uniformly over all sampled depths. From the plots of depth distributions (Figure 15), it is seen that all but Reach 2 and Reach 4 depths are skewed to shallower or deeper depths. Reach 1 is skewed towards deep water, which gives a safety factor for travel through the channel. Reach 3 is clearly skewed towards shallower depths, indicative from the skewness of -1.3, but Reach 5 looks as though it is skewed towards deep water, despite a skewness of -1.2. Examination of the table of depths for Reach 5 (Appendix E: Table E1) shows that there is a spread of depths into very shallow water, giving the negative skewness coefficient. This skewness is perhaps contaminated by the slumping channel margin at Station 122+00.

March 1989

The cruise from March, 1989, shows average depths again on the order of 51 feet (Appendix D: Table D2). Reach 3 has the minimum average depth. Reach 5 shows the greatest variability in depths. Depth in all reaches except Reach 4 are non-normal. Depths in Reach 4 have a near-normal distribution. Reaches 3 and 5 are again skewed towards shallow water from the mean. Reach 1 has a low kurtosis, even though it exceeds the limits for normality. This can be seen in Figure 9 by the relatively flat distribution across depths of 50 to 55 feet. If this is compared with January, 1989, Reach 1, the shape is fairly consistent. This would suggest that Reach 1 is inactive, at least between these two surveys. Station 284+00 (Appendix G: Figure G2) shows the local variations and the need for several sources of data when looking at channel bathymetry. The extreme depth change at range 1000 for Station 284+00 does not show up in the March 1989 smooth sheet, nor does it impact the contour map of the settling basin. What was discovered when interpreting the data was that those points making up the spike were part of a run along the longitudinal channel axis. With predominant wave propagation from the northeast on that day of surveying, an excessive ship roll could have given a fathometer return on the channel slope rather than the bottom. The mild winter during the year did not produce any major storms capable of moving large amounts of sediment, but the tidal dynamics have shifted Reach 5 towards shallow samples, suggesting a need to dredge. Another indication for dangerous channel character would be a negative high kurtosis coupled with a negative skewness, meaning that there is a uniform spread of depths shallower than the sample mean, and these depths are occurring almost as often as the mean depth, making it difficult to navigate. This condition was not apparent in any of the March 1989 data.

May 1989

The Spring cruise showed the same tendencies as the first two, with the characteristic lowest average depth in Reach 3 and high spread in Reach 5 (Appendix D: Table D3). Reach 3 has an average depth below 50 feet. Kurtosis in Reach 2 shifted from 11.5 in March to 2.3 in May. Looking at Figures 16 and 17, the May distribution appears more kurtotic than March, but the coefficient has dropped significantly between the two months. This shows that the distribution of depths about the mean and the accompanying standard deviation are important when the kurtosis coefficient is evaluated. Although the March depth distribution appears flatter than that in May, the samples grouped at 51 and 52 feet comprise 60% of the total sample. The May distribution has a 37% sample volume at 51 feet, with 25% of the sample at 52 feet. Evidently the high grouping of samples in the March distribution was responsible for the high kurtosis coefficient.

June 1989

Dredging was done in June during the survey, between stations 21+800 to 32+900. This dredging contaminates direct comparison between May and June, but shows up in the statistical results. The dredging lowered the skewness in Reach 5, also lowering the kurtosis. This is a result of the removal of material that had collected at Station 122+00. Note that Reach 4 has increased to a high kurtosis; looking at the histogram values in Appendix E: Table E4, the new behavior in June is a grouping of fairly level depths about the mean from depths of 50 to 55 feet. The peak is not as pronounced as in May, which had a sharply increasing sample count towards the peak. From this example and the one mentioned above for Reach 2 kurtosis levels, a high kurtosis is characterized by grouping of uniform depths distributed within the standard deviation of average depth. This type of channel character would be safely navigable as long as average depths were acceptable and spreads were within safe bounds.

September 1989

The survey results show a decrease in average depth of 1.4 feet between the June and September surveys in Reach 5 (Appendix D: Table D5). Kurtosis is high again in Reach 5, but has dropped in Reach 4. This behavior of erratic kurtosis in a sample region through time would suggest that the channel slopes might be encroaching on the margins. This has been seen in the smooth sheet printouts for Reach 4 with a large shoal on the north side of the channel that appears to feed the channel with sediment continually. Note the minimum depth in Reach 4 is 25.6 feet for June, at Station 19+237 on the north side. There is no such "spillage" in September. These differences are also mildly displayed in standard deviation, where June's exceeds September's by one-half foot. When interpreting these data, it is important not only to look at statistical quantities, but the distributions, dredging information, and smooth sheets.

October 1989

Hurricane Hugo passed through the area in late September, 1989. The modal wave period for this major event was 10 seconds, not abnormally long but sufficient to move sediment. As shown in Appendix D: Table D6, the largest change for September is that most Reaches have shallower average depths by roughly a foot. In Reach 1, there is little difference in depth. Standard deviations give no hint of storm effect, but the skewness and kurtosis coefficients in Reach 3 are within normal bounds. Figures 19 and 20 for the depth distributions between September and October show Reaches 3 and 5 have gone through some changes. Reach 3 has a flatter distribution over shallow depths in October, with 12% of the samples occurring at the 46 foot depth. An appreciable amount of the channel is barely above the control depth limit. Reach 5 experienced similar spreading, which is probably due to the high energy within the jetties during a storm. With the decreased average depth, and evidence that sediment has been placed at shallower depths in Reaches 3 and 5, the question is whether this was a simple transfer of sediment within each reach due to higher waves, or an intrusion from an outside source. The survey smooth sheets from October show a general accretion in the northern part of the survey area outside of the channel. Since Hugo passed to the north of St. Marys Inlet, waves would have been travelling from the northeast, and a longshore current could have been established from that direction. Thus large amounts of sediment could have been transported from the north into the survey area, then trapped in the channel.

January 1990

After the hurricane, emergency dredging operations commenced in Reach 3. This restored the average depth to an acceptable level. The standard deviations (Table D7) are high, however, suggesting either dredging effects or bedforms in the channel. The histograms (Fig. 21) for Reaches 2 through 5 have interesting shapes, confirming the high standard deviation. Dredging operations were isolated, which supports the presence of another process giving the channel an uneven character. Texture maps were done in the settling basin only, but give little hint of large bedforms except in Reaches 4 and 5 where S2 and S3 sand waves exist. Dredge marks extend from Reach 4 into Reach 3. The texture leading into Reach 2 is usually mottled with no distinguishing trait.

June 1990

The histograms (Figure 22) have returned to the more common shape from the double-peak form seen in January, 1989. This is evident in the higher kurtoses (Table D8) which suggest a closer grouping of depths about the mean. This is also evident by the smaller standard deviation from the mean depths in the Reaches. The skewness was most Reaches is non-normal, Reach 2 having a normal distribution. The kurtosis was normal in Reach 1, non-normal in the others. Reaches 1 and 2 had the highest 99th percentile depth since September, 1989. The large spread in Reach 5 translated into a low 99th percent depth of 37 feet.

4.3 SEDIMENT TRANSPORT MODEL

Because wave conditions were benign during the study, they do not provide adequate estimates of channel shoaling rates during major storms. To address this storm shoaling rate, a diagnostic numerical model was applied to the Kings Bay entrance channel, using simplified bathymetry, idealized wave and current forcing, and a standard sediment transport relationship.

Two forms of coarse sediment transport occur at Kings Bay: bed-load and suspended load. The transport rate depends on the bottom velocity, grain size, roughness of the bed, and turbulence in the boundary layer. Referring to bed load discharge as q_b and the suspended load as q_s, the total sediment discharge is $q_t=q_b+q_s$ which has units ($m^3/m/s$). The bedload discharge due to waves and currents can be defined by a modified Kalinske-Frijlink equation as

$$q_b = 5D_{50}\frac{U}{C}\sqrt{g}\,\exp\left[\frac{-0.27\Delta\rho D_{50}C^2}{\mu U^2\left(1+\frac{1}{2}\left(\frac{C\sqrt{f_w}\hat{u}_b}{\sqrt{2g}\,U}\right)\right)}\right] \qquad (8)$$

where,

D_{50} = mean grain diameter
D_{90} = Grain diameter at which 90% is coarser by weight
U = mean above-bed velocity
$C = \log(12h/k_s)$
$C' = \log(12h/D_{90})$
h = water depth
k_s = amplitude of sand ripples
$\Delta\rho = (\rho_s - \rho_w)/\rho_w$
$\mu = (C/C')^{3/2}$
f_w = friction coefficient
$\hat{u}_b$ = maximum near-bed orbital wave velocity

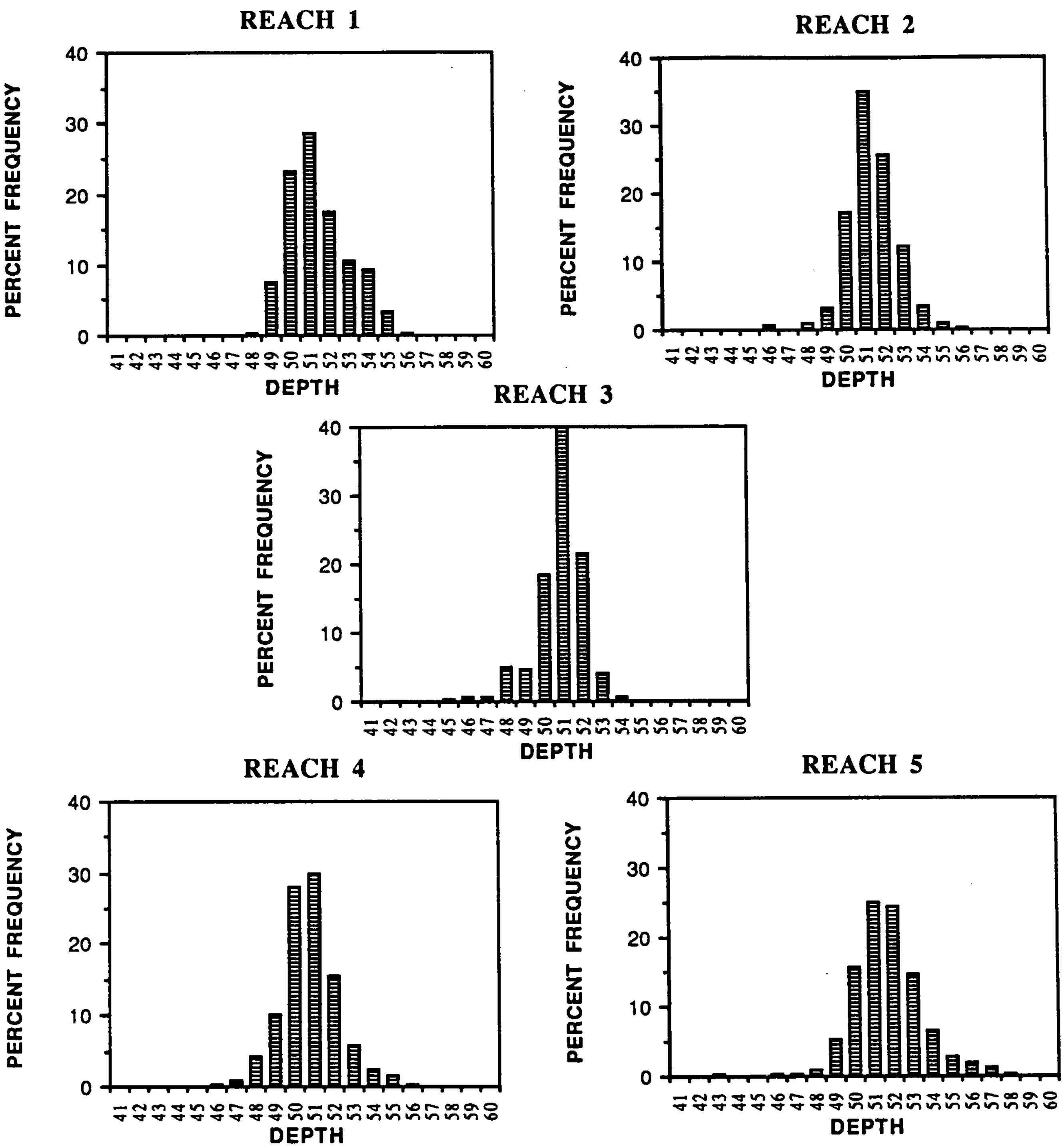


Figure 15. Histograms of depth (ft) for January, 1989

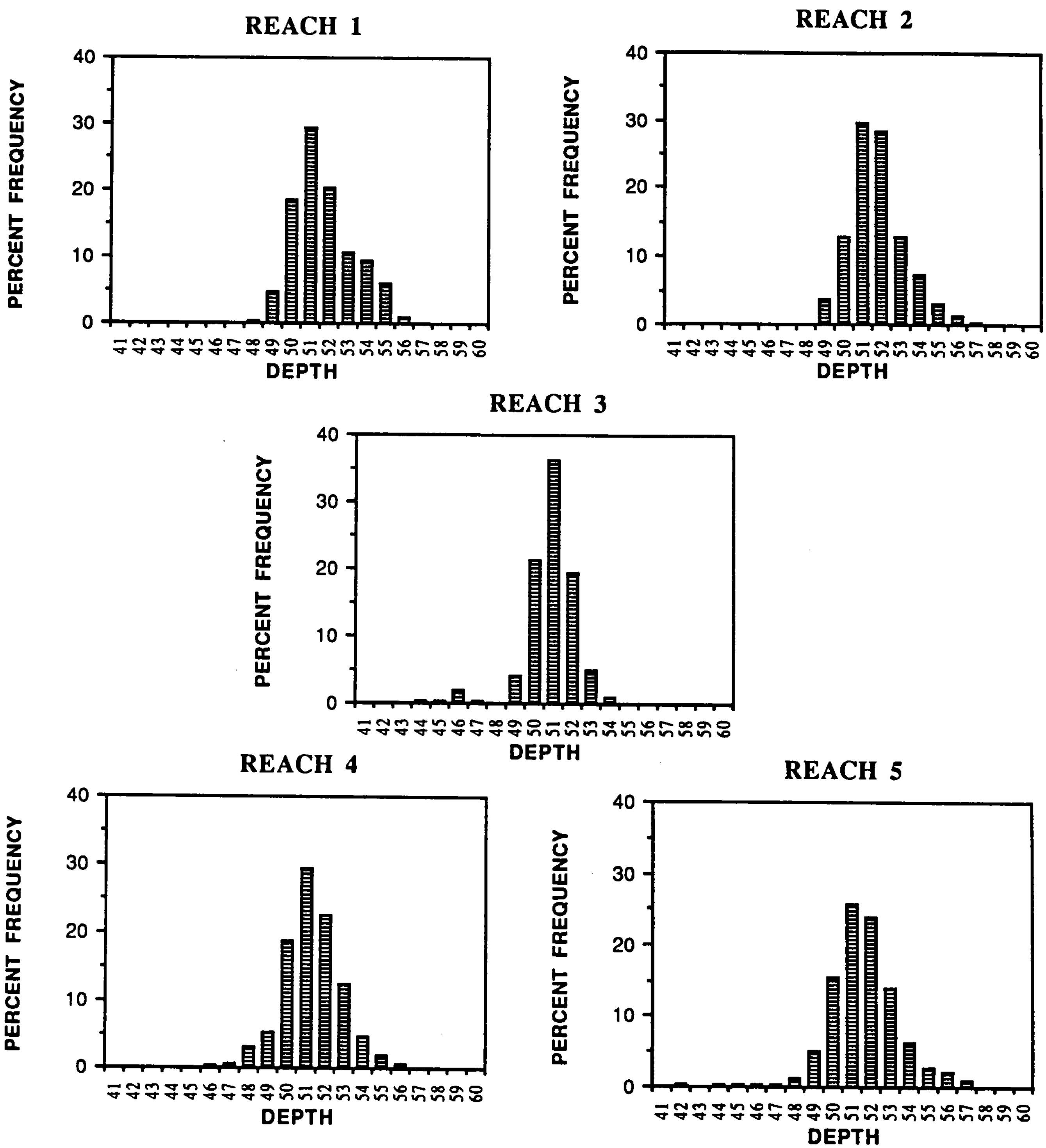


Figure 16. Histograms of depth (ft) for March, 1989

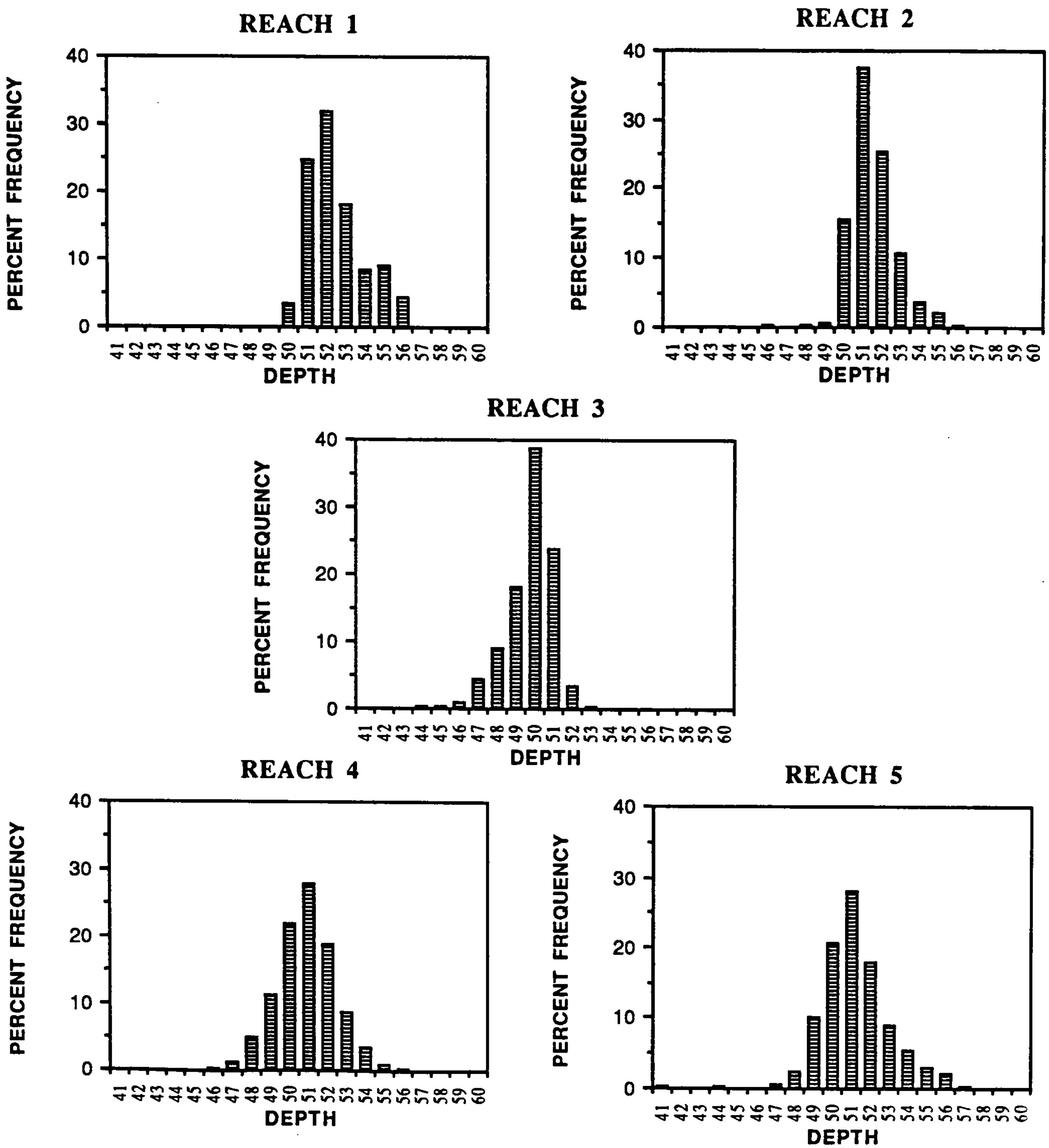


Figure 17. Histograms of depth (ft) for May, 1989

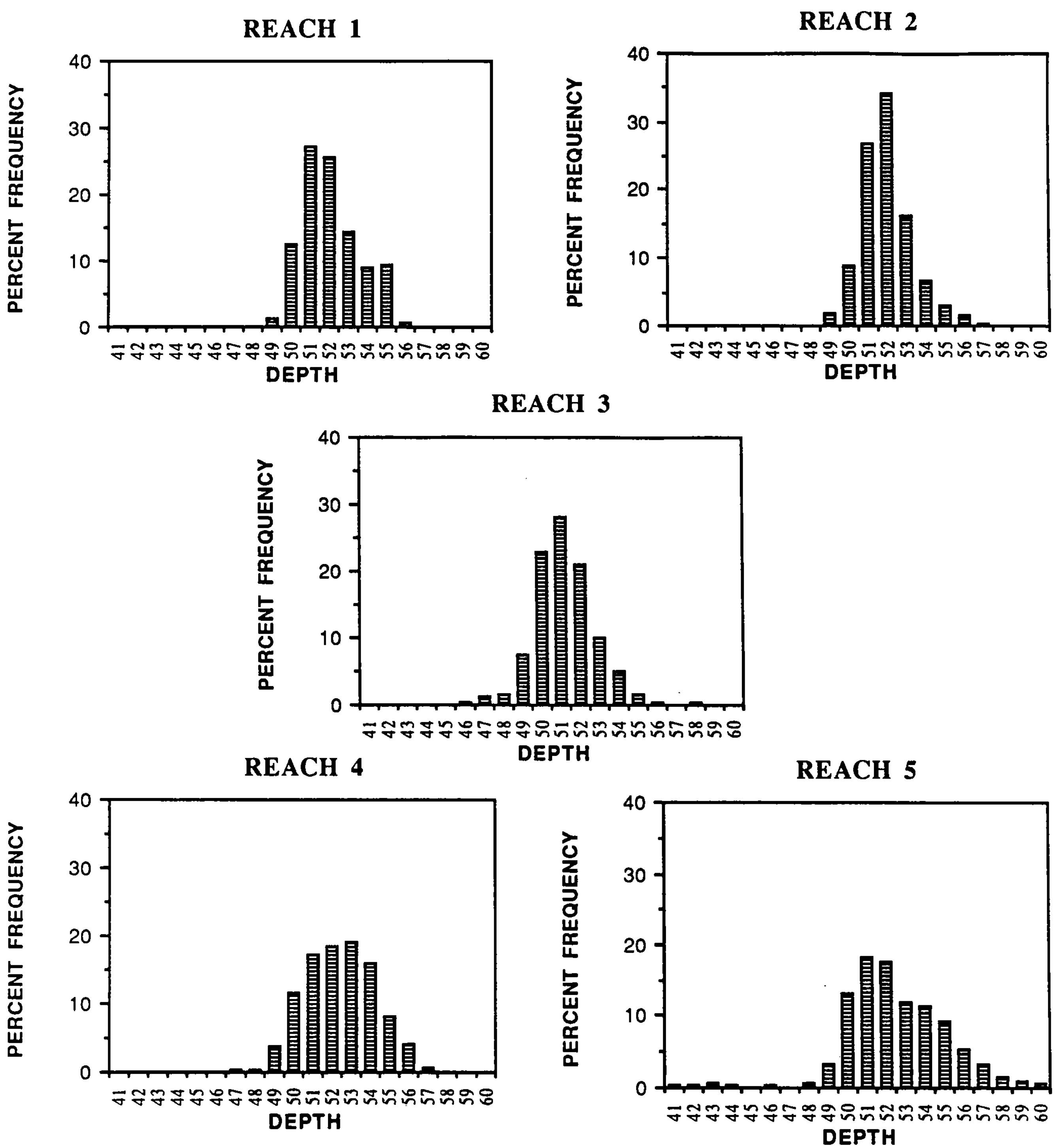


Figure 18. Histograms of depth (ft) for June, 1989

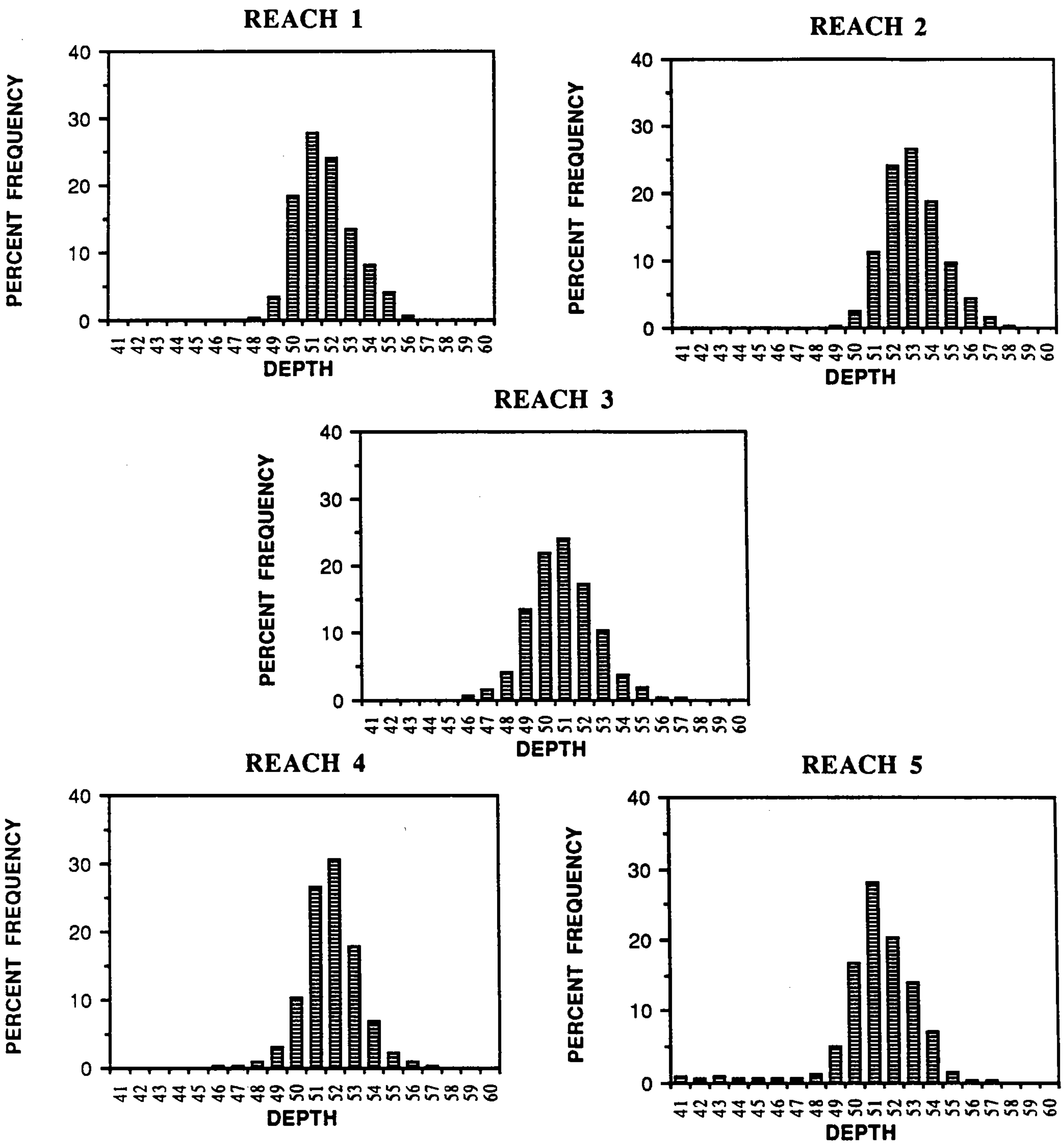


Figure 19. Histograms of depth (ft) for September, 1989

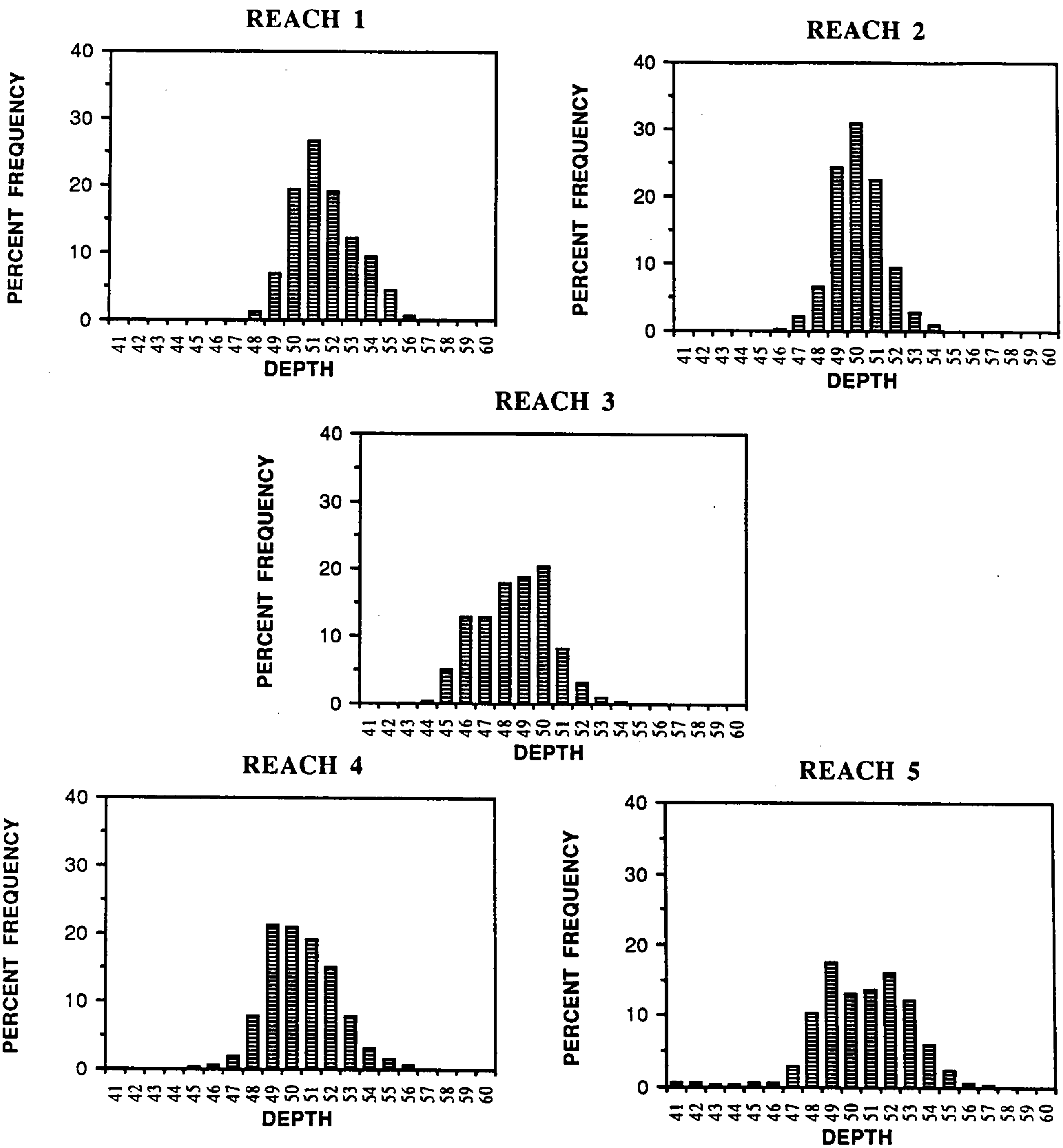


Figure 20. Histograms of depth (ft) for October, 1989

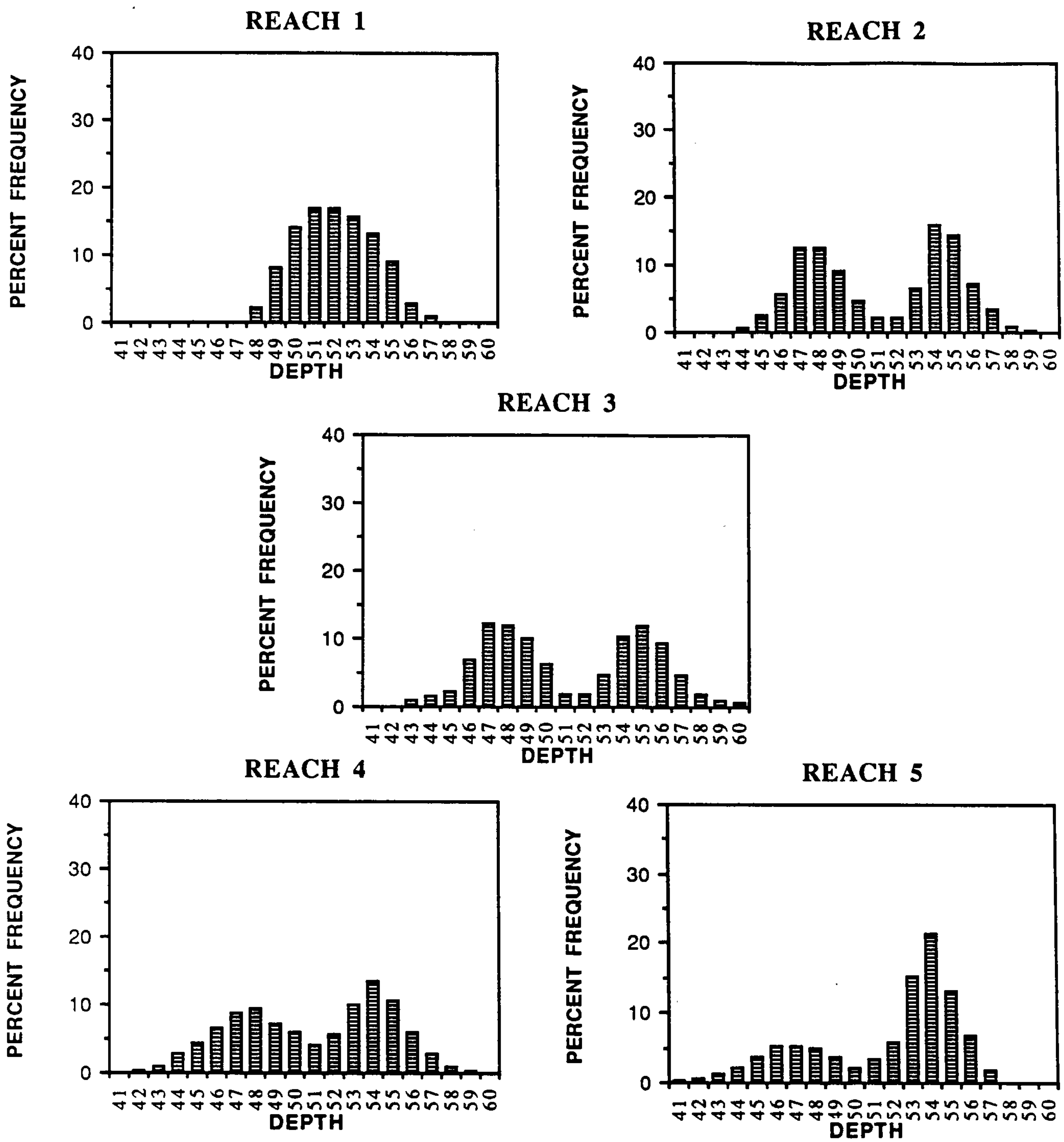


Figure 21. Histograms of depth (ft) for January, 1990

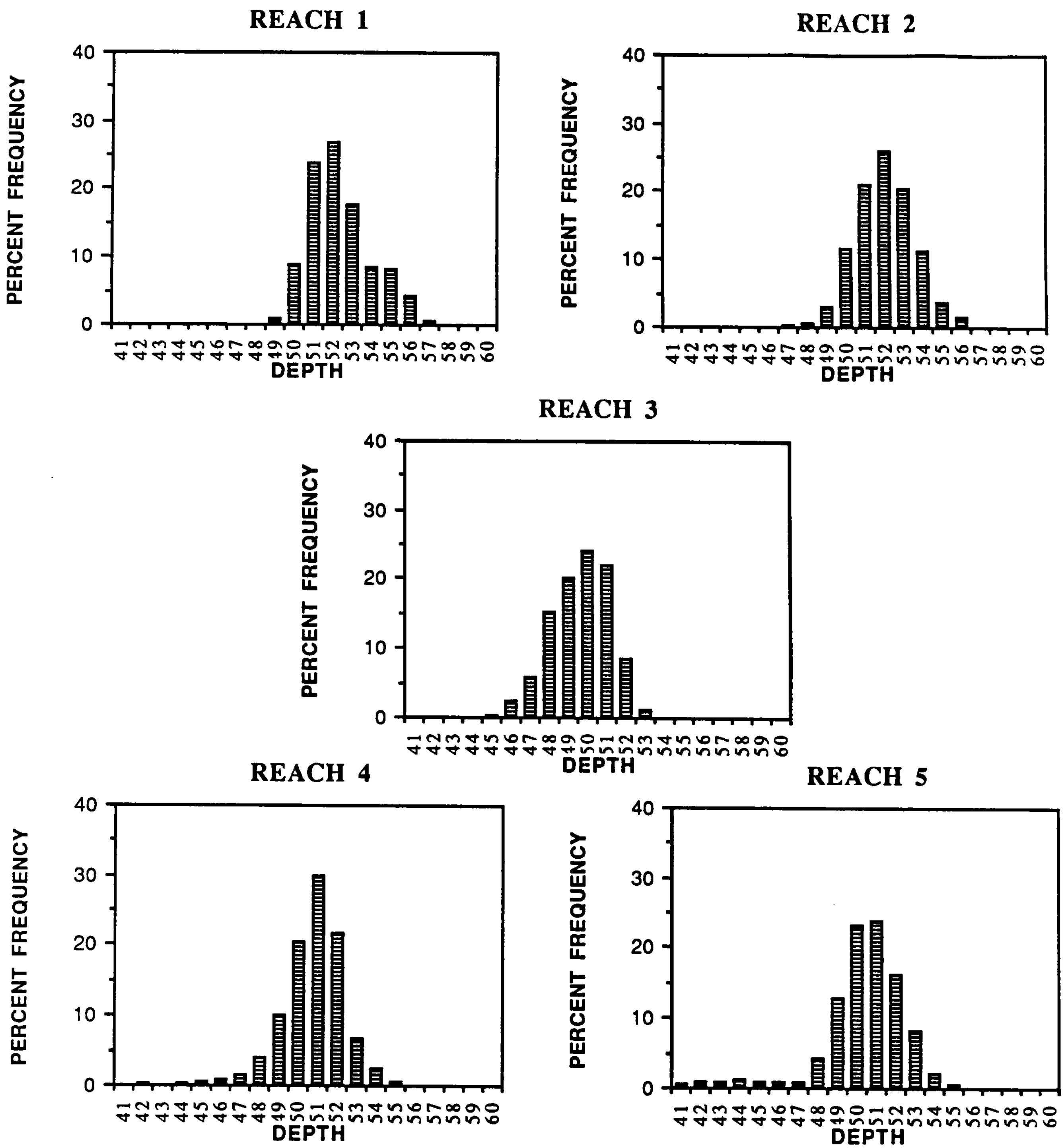


Figure 22. Histograms of depth (ft) for June, 1990

The sediment discharge can be represented by a sediment conservation equation:

$$\frac{\partial \zeta}{\partial t} + \frac{\partial q_b}{\partial x} + \frac{\partial q_b}{\partial y} = 0 \qquad (9)$$

The conservation equation does not consider any source terms of sediment input in each cell. The sand level is denoted as ζ. This partial differential equation can be solved using a simple finite-difference explicit method over a non-staggered 2-D grid (Koutitas, 1988). Wave and current angles are handled by considering a two-component discharge q_{bx} and q_{by} defined by specifying the velocity components for the steady and orbital velocities as:

$$U_x = U \cos(\theta_t)$$
$$U_y = U \sin(\theta_t) \qquad (10)$$

$$\hat{u}_{bx} = \hat{u}_b \sin(\theta_w)$$
$$\hat{u}_{by} = \hat{u}_b \cos(\theta_w) \qquad (11)$$

where θ_t is the steady current heading and θ_w is the wave direction. The finite difference form of (9) is then

$$\frac{\zeta_{i,j}^{n+1} - \zeta_{i,j}^{n}}{\Delta t} = -\frac{q_{x,i,j} - q_{x,i-1,j}}{\Delta x} - \frac{q_{y,i,j} - q_{y,i,j-1}}{\Delta y} \qquad (12)$$

with the subscript eliminated. The flow chart for the FORTRAN program of the model is given in Figure 23. The bathymetry for Kings Bay was idealized to include cells of 1000 feet by 500 feet and is shown in figure 24. The mean current was specified as uniform over the grid except for the cells closest to the shoreline. From station 91+00 to station 71+00 the current amplitude dropped linearly from the maximum to zero. There is no refraction of waves, thus wave angles were uniform over the grid. The input characteristics are specified in Table 7.

TABLE 7
INPUTS TO THE SEDIMENT MODEL (SI Units)

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
D_{50}	0.0005 m	D_{90}	0.0005 m	U_{max}	.5-1 m/sec	k_s	5 cm
ρ_s	2.65 g/cm^3	ρ_w	1.03 g/cm^3	f_w	0.01	g	9.81 m/s^2

The results from the model are shown in Figure 25a-c. The graphs are of net sediment erosion or accretion for different inputs depending on station. Refer to Table 1 for the relation between station number and reach. All tests were run with the usual wave direction of 100° and a mean current heading from north to south over the grid. The wave height in the last test was 30 feet with a period of 20 seconds, what would be considered a large event to suspend sediment above the bed. The mean current of 0.97 knots was high in the north-to-south direction but was used to prove that the physics involved failed to move sediment on the order that is observed in the field. The volume change occurred at the northern channel slope due to the high mean current, a worst case scenario for Kings Bay. The stronger tidal currents are more along the channel axis. With the sediment transport into the channel as it occurs in the field, another transport mechanism must dominant. Thus, the major sediment supply appears to come not from bedload sediment across a flat bed, but rather from movement of shoals towards the channel from the north. There is no adequate theory to estimate shoaling rates due to these processes.

DISCUSSION

During the EMOGS sedimentation program, 13 bathymetric surveys were accomplished. Data from these surveys formed a data base with which to evaluate the sedimentation associated with the Kings Bay entrance channel deepening. It is widely considered that a deeper entrance channel will accelerate sedimentation rates, increasing the maintenance dredging requirements. These data provided the basis for quantifying such rates at Kings Bay.

One concern expressed early in the sedimentation phase was the existence and persistence of bedforms (sand waves) within the entrance channel which might affect transit of ships. Such large-scale bedforms, having heights of 6 feet or more, have been documented in many entrance channels. The textural and depth mapping of this program showed persistent bedforms of heights of 3 feet or less, but none having greater height within the entrance channel. Outside the entrance channel, bedforms were large, exceeding 10 feet in height (shoals). We attribute this lack of large bedforms within the channel to two factors: strong current flow and frequent maintenance dredging leading to disequilibrium conditions for much of the time where the bedforms otherwise might be expected to occur.

Rates of channel sedimentation were determined from comparison of successive surveys. Hurricane Hugo's passage in 1989 provided the maximum observed sedimentation, approximately 1 foot throughout the channel, and locally up to 2.5 feet and more. Such aperiodic sedimentation events are difficult to plan for and to respond to. During the period of study, wave climate was benign due to sparseness of large storms. The largest wave measured offshore during this interval was 14 feet, less than half the size of the maximum wave expected during a major storm. Sedimentation following this storm was on the order of half a million cubic yards; a major storm could exceed this measured sedimentation by a factor of three or more.

To provide guidance to the fleet for sedimentation, several measures of sediment activity were determined:

- Hotspots: hotspots were located where increased sedimentation is expected and where attention should be focused. Hotspots were confined primarily to the sedimentation basins provided by the dredging, on the north side of the entrance channel in reaches 4 and 5. However, another hotspot was identified along the north side of the channel near the boundary between reaches 3 and 4. Here there is no sedimentation basin, and the sediment from a migrating shoal enters directly into the navigation channel. Dredging during the past three years has been confined primarily to this area. In the future, these hotspots should continue to be monitored carefully, especially after storms.

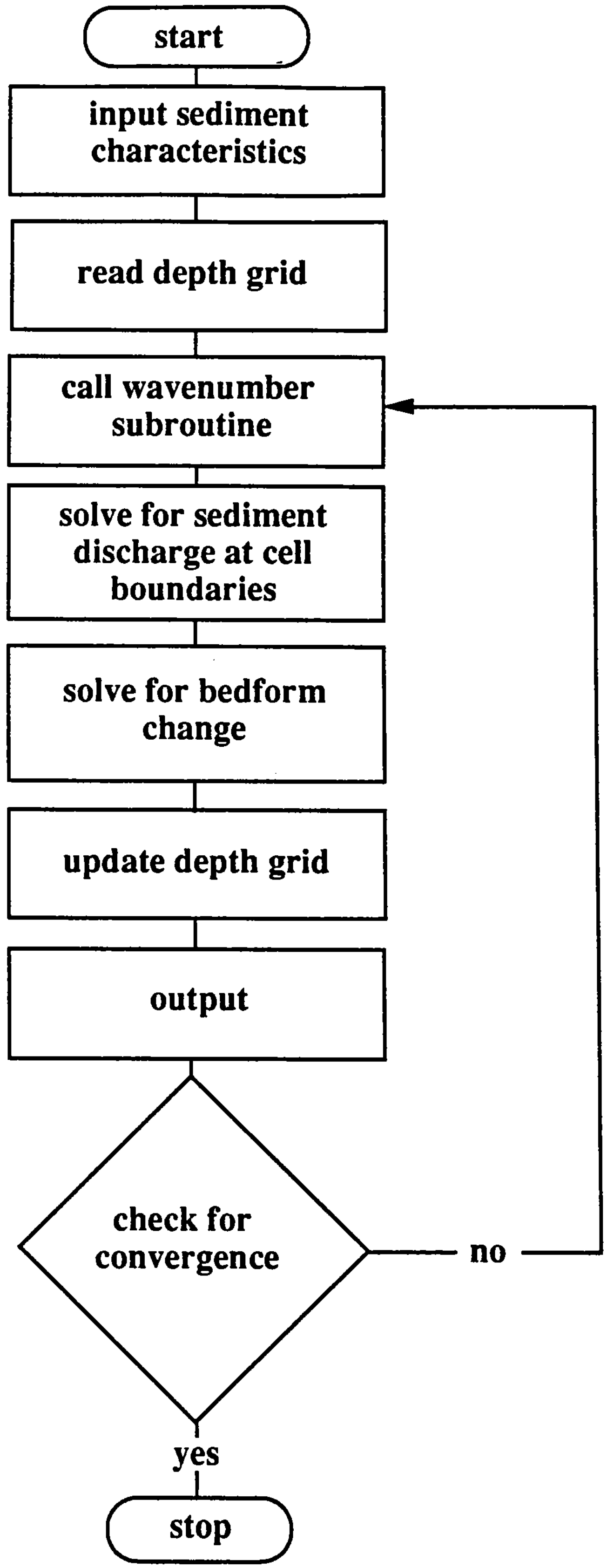


Figure 23. Flow chart for sediment transport model.

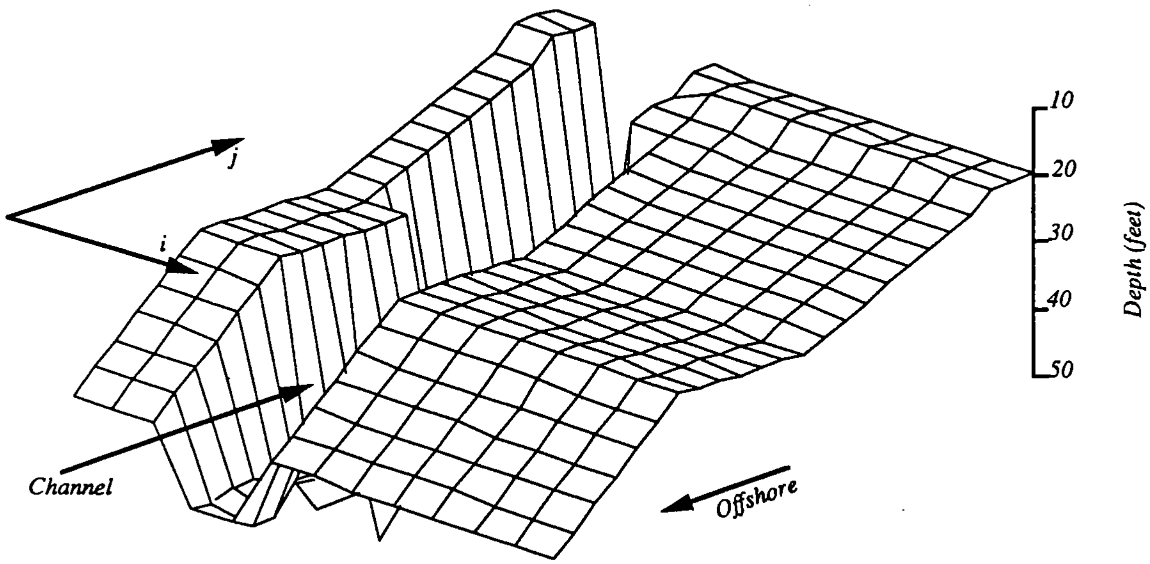


Figure 24. Bathymetry input to the model.

• An activity parameter was defined based on observed changes between surveys. This activity parameter indicates areas within reaches 3 and 4 where sedimentation is taking place. The activity parameter for reach 1 is low, indicating low sedimentation rates here during the study. However, a major storm could produce major sedimentation changes here as well. This activity parameter provides a useful measure of sedimentation potential, and hence of threat to navigation.

• Survey results are analyzed with a many-faceted statistical model, to derive estimates of sedimentation potential within each channel reach for various survey intervals. This statistical model was installed on the Army Corps of Engineers' computer in Jacksonville, FL, to enable them to generate similar statistics following their surveys of the channel in the future.

• A diagnostic numerical model of sediment transport was developed to extend the prediction of sedimentation rates within the channel during large storms. This model is required because the waves occurring during the study were lower than extreme conditions, and hence do not reflect the maximum sedimentation potential. A combined wave/current numerical model of sediment transport was applied to the channel region. The model, although simple, includes much of the germane physics. However, it does not adequately describe the movement of shoals, which appears to be a primary transport mechanism at this location. Thus, the model is not useful for predicting in a quantitative fashion the expected sedimentation rates during storms; however, the model does show that extreme waves will transport at least an order of magnitude more sediment than the wave conditions experienced during the study. The lack of quantitative agreement is expected, since our understanding of sediment transport processes within tidal inlets is inadequate and must be improved.

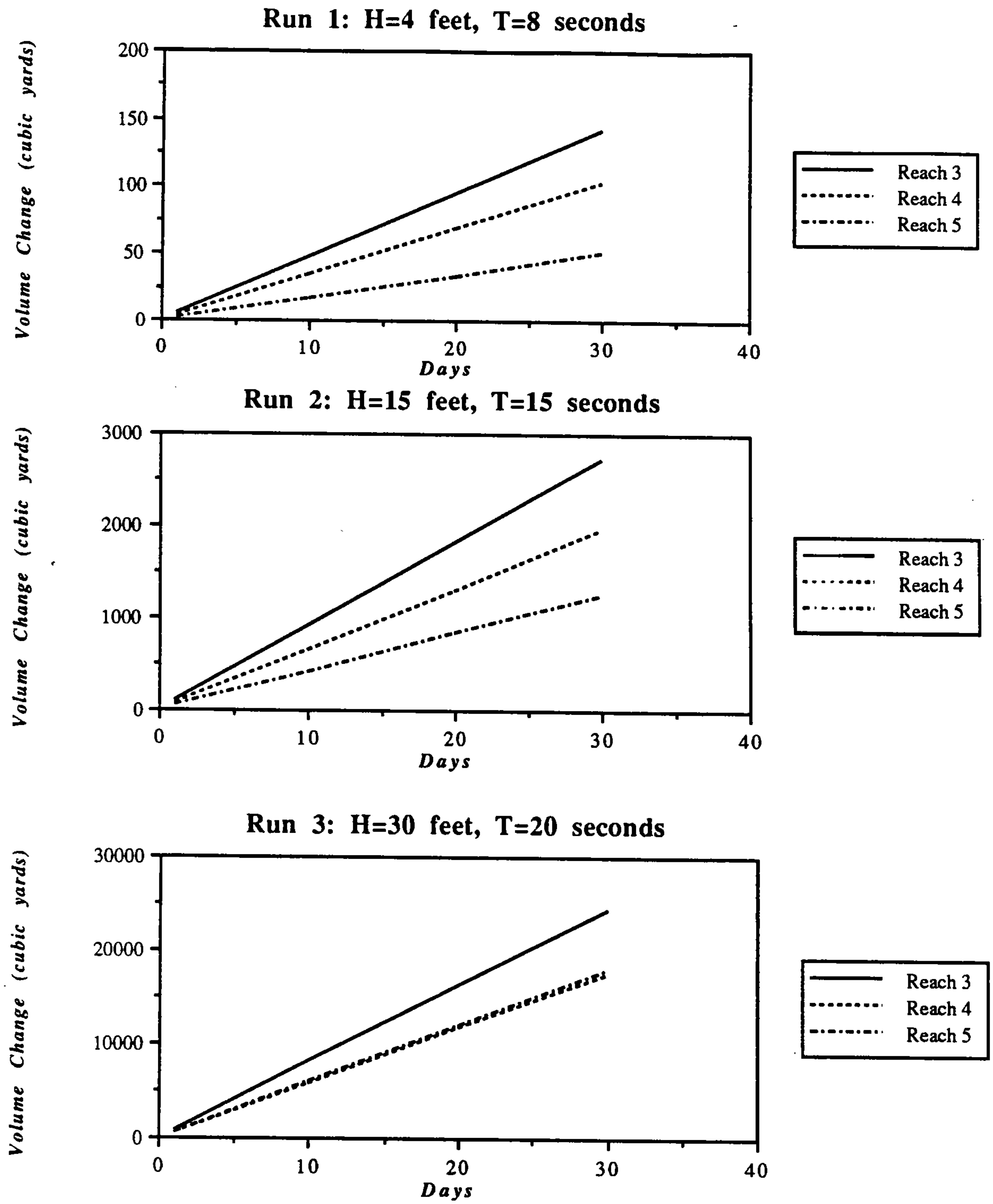


Figure 25 a.) H_S = 4 feet, T=8 sec b.) H_S = 15 feet, T=15 sec
c.) H_S=30 feet, T=20 sec

The recommendations are that:

• Some form of sedimentation monitoring be continued, especially near the hotspots and after storms, to provide operational guidance for navigation conditions. Several alternatives for this monitoring using currently available technology exist.

• Real-time wave information be collected and stored routinely, for comparison with sedimentation rates. In the future, these data along with bathymetric data will clarify empirically the sedimentation rates and processes within the channel.

• The Navy focus on improving our ability to predict quantitatively the sedimentation within entrance channels, perhaps by contribution in some fashion to a major engineering initiative on flow and sedimentation processes in inlets, now anticipated by the Corps of Engineers.

• Continued special attention paid to areas adjacent to the channel as prescribed in the December 12, 1989 meeting at COE Jacksonville by David Taylor Research Center and Woods Hole Oceanographic Institution. The following is a summary of those recommendations:

1.) Run cross-sections at 100 foot intervals between stations 210+00 and 340+00.
2.) Run long cross-sections every 300 feet between stations 210+00 and 340+00 so that they extend from ranges -250 to 3250.
3.) Between stations 210+00 and 340+00, three longitudinal lines are to be run along ranges 250, 1750, and 2750.
4.) Between 0+00 and 210+00 and beyond 340+00, five longitudinal lines are to be run at ranges 800, 900, 1000, 1100, and 1200.
5.) Run a cross-sectional line every 500 feet along the survey from the top of the slope on the north side of the channel to the top of the slope on the south side.

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APPENDIX A
SURVEY SYSTEM
EMOGS SEDIMENTATION STUDY
WOODS HOLE OCEANOGRAPHIC INSTITUTION

Four major components make up the EMOGS bathymetric survey system (Table A1):

1) Navigation: A UHF navigation system that was installed and is maintained by the USACE forms the basis for all navigation for the surveys. A UHF master transponder and DDMU (Digital Distance Measuring Unit) are the sea-borne components. Range accuracies for each remote transponder are approximately 0.5 to 1 m. However, positional accuracy depends strongly on the geometry of the stations, and on how well the network is maintained (tuning of the transmitters, integrity of the sites, etc.).

2) Fathometer: A dual-frequency, survey-quality, echosounder operating at 24 and 200 kHz was selected for the bathymetric surveys. One or both of the frequencies can be activated at any time; the use of dual frequency provides a means for evaluating the presence of soft sediments on the bottom. These data are digitized and fed into the survey computer hardware and software. A two-way communication allows the computer to control the time base of the fathometer, and to annotate the fathometer with time, position, and other information.

3) Side-scan sonar: A state-of-the-art, dual frequency, side-scan sonar was purchased to provide textural information and swath mapping of the channel off Kings Bay. The side-scan operates 100 and 500 kHz signals simultaneously, recording both on magnetic tape (FM recorder) and on thermal paper for a high resolution, broad bandwidth record of bottom backscatter. These data indicate the length scales of bedforms present in various parts of the entrance channel, and show other changes in bottom texture (grain size, sorting, etc.). This is the primary tool for mapping bedforms in the channel.

4) Data acquisition system: The hardware and software system selected for data acquisition is the SAIC INDAS system, consisting of HP computers and plotters and a specialized survey software system. The data acquisition system software includes synchronization capabilities for side-scan and echo-sounder while surveying in the field, as well as the storage of time, depth, and position information. The post-processing software contains numerous options, including the output of standard, tide-corrected bathymetric plots, three-dimensional bathymetry plots, contour maps, and volume-difference calculations for between-survey comparisons.

In addition to the four primary components listed above, a number of other smaller components are required, including generator, power supplies, etc. which support the above components. All surveys to date have been conducted on the vessel *Sis,* owned by Bill Kavanagh and operated out of Fernandina Beach, Florida.

TABLE A1
EMOGS NAVIGATION SYSTEM COMPONENTS
SEDIMENTATION STUDY

<u>Del Norte Navigation System</u>

Del Norte model 547 DDMU
Del Norte Model 547 Master Transponder
Del Norte model 547 Antenna

<u>ODOM Hydrographic Systems Fathometer</u>

ODOM Echotrac Model DF-3200 Control Unit
Dual Frequency (24 kHz, 200 kHz) transducer, model 210-33/9-19

<u>Side Scan Sonar System</u>

Klein Digital Side Scan Recorder: Model 595
Klein Dual Frequency (100 kHz, 500 kHz) towfish, model 4225-101HF
Hewlett-Packard 1/4" magnetic tape recorder, model HP396YA

<u>SAIC Integrated Navigation and Data Acquisition System (INDAS)</u>

Computer Hardware	Computer Software
HP 9920S Computer	INDAS Real time navigation software
HP 98256A RAM	INDAS post-survey processing software
HP 9153C-010 Disk	
HP 82913 Monitor	
HP 93526A Serial	
HP 2225A ThinkJet Printer	
HP 7475A Plotter	
HP 7596A Plotter	
HP 10833C HPIB	

APPENDIX B
ST. MARYS ENTRANCE CHANNEL
TIDAL DATA

Enclosed is an explanation of the method we have employed in obtaining tidal data for St. Marys Entrance Channel at King's Bay, Georgia. This method has proven most expedient in our previous bathymetric surveying operations and therefore we plan to continue with this method in our future work, unless an improved method is tested and proven.

From personnel under the supervision of Elmo E. Long, the Acting Chief of the Tide and Current Prediction Section at the National Ocean Service in Rockville, Maryland, we obtain tables, in ten days or less, with hourly tide predictions for all the days in any month at a service charge of ten dollars. The tide predictions are based on harmonic constants for a station nearby on the Amelia River in Fernandina Beach. The harmonic constants enable tide predictions for the Amelia River station to be calculated. Then, with known (previously measured) time differences and height ratios for high and low water, the times and tide levels at high and low water can be calculated for the North Jetty at St. Marys Entrance Channel. Tide levels between high and low water at the North Jetty are then calculated by interpolation along a cosine curve.

This procedure yields hourly tide predictions for the North Jetty location in St. Marys Entrance Channel at Kings Bay, Georgia. We have compared this output with tidal output acquired by *in situ* tide gauges provided by the Army Corps of Engineers from two locations in St. Marys Entrance Channel (Stilling Well, Telemetry Station). The results of this comparison were satisfactory with a ten-day test period showing maximum differences of only one foot between the calculated tidal predictions and both physical measurements of the tide at the two different locations.

Previously, there had been concerns regarding tidal data for St. Marys Entrance Channel. One concern had been that *in situ* physical measurements would be required for accurate tidal information. A second concern involved whether tidal characteristics varied significantly between the area inside the jetties and the area outside the jetties at St. Marys Entrance Channel. The results of the comparison discussed above addressed both these issues since one of the physical tide sensors (Stilling Well location) operated by the Army Corps of Engineers is located inside the jetties and the other (Telemetry Station location) is located outside the jetties at St. Marys Entrance Channel. The comparison indicated tidal characteristics are similar, and vary less than one foot the vast majority of time.

Based upon information available to us up to this time, we have selected the method of tidal correction based on the predictions from harmonic constants at Amelia River provided by the National Ocean Service. Although such predictions are not able to account for local meteorological effects on the tide, such as set-up, we assume that survey work will not be undertaken during times (e.g., storm conditions) when meteorological events are expected to have a *significant* effect on the tide. During the early period of our research involvement, we found that the tide-gauge operation of the Army Corps of Engineers was not a feasible means to obtain consistent tidal data due to unpredictable periods of both instrumentation inaccuracy and instrumentation down-time. As this condition has changed, we have begun to modify our operations accordingly.

The National Ocean Service has made available to us both the harmonic constants at the Amelia River station and the offsets to the North Jetty at St. Marys Entrance Channel. With existing software developed at WHOI, we have the capability to generate the tidal predictions ourselves in the future, for inclusion in EMOGS.

APPENDIX C
SIDE-SCAN DATA INTERPRETATION

Side-scan sonar data must be interpreted in a descriptive fashion to document textural differences along the bottom. Factors affecting this interpretation include variability in the manual tuning of the side-scan hardware, variability in the water quality due to the effect of the tide on suspension of particulate matter, variability in towing dimensions of the fish (side-scan transducer body) due to the restrictions of water depth, and finally the subjective nature of classifying the continuum of bedform textures into distinct categories. As we gained more experience from working with the side-scan data from Kings Bay, we refined our classification scheme of the bedform textures to meet both the difficulties of interpretation and the overall goals of our analysis. This accounts for the more detailed legends on the more recent texture maps from our side-scan work. To distinguish textures from side-scan records, bedforms were scaled by their lengths, since bedform height is more difficult to measure from a side-scan image. Fathometer traces over bedforms are contaminated by wave motion and ship motions, so they are not useful to show bedform height. The classification to be discussed below includes the following elements:

a) Developing bedforms: These bedforms are not well-formed, or are not imaged well by side-scan. In general, these bedforms show less coherence than developed bedforms.

b) Developed bedforms: These forms show spatial homogeneity and coherence (wavelengths of 0.5 - 12 feet and greater). Bedforms with wavelengths of one to six feet are shown in Figure C1, with a 15 meter distance between scale lines. Bedforms having lengths between six and twelve feet are exemplified by Figure C2, where the distance between scale lines is 15 meters. Bedforms having wavelengths greater than 12 feet are shown in Figure C3, where scale lines again are separated by 15 m. Note that the fidelity of the bedform image is affected by look angle (one image is always better than the opposite image).

c) Dredge marks: The many dredges operating in the area left large scars, particularly where the hopper dredges worked. These are imaged well by the side-scan (Fig. C4). Their distinctive geometry make them easily recognizable by side-scan sonar.

d) Mottled bed: Often, bedforms cannot be distinguished because of lack of coherence, fineness of sediments, or because bedforms are not present. Figure C5 shows a mottled bed, consisting of several different types of reflectors, none of which is regular.

e) Specific features: Occasionally, specific features such as the end of the jetties are distinguished in the side-scan images. These features are marked on the texture maps. The anchor and chain to a buoy are indicated on Figure C6, as imaged by side-scan.

f) Dredge interference: Suspended sediment from the dredging operations (particularly the hopper dredges) degraded signal quality on the early surveys in particular, but in all surveys to some extent. Suspended sediment near a hopper dredge can block all returns within the channel.

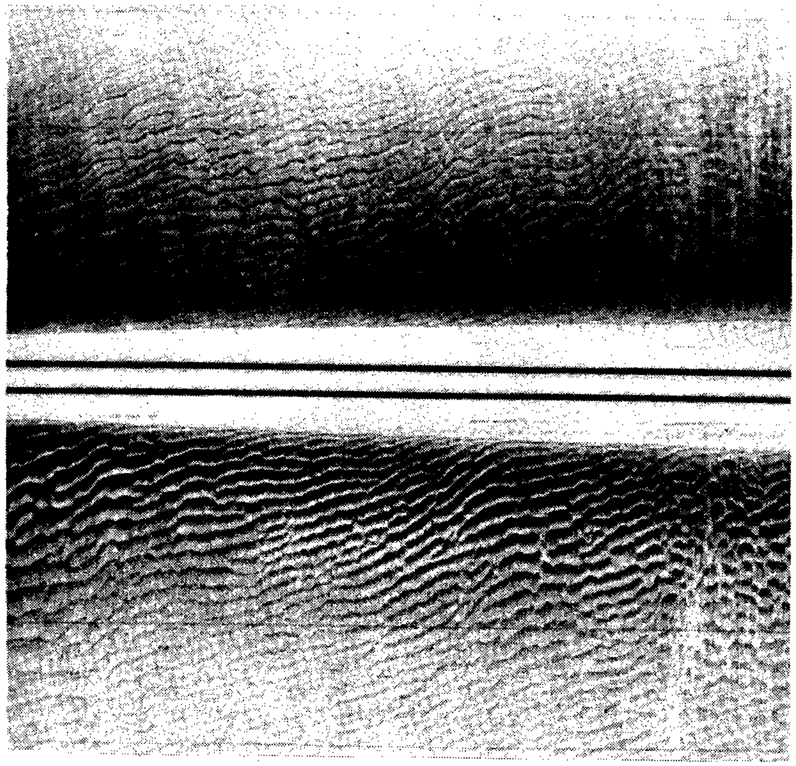


Figure C1. Side-scan return of S1 sand waves with wavelengths of one to six feet

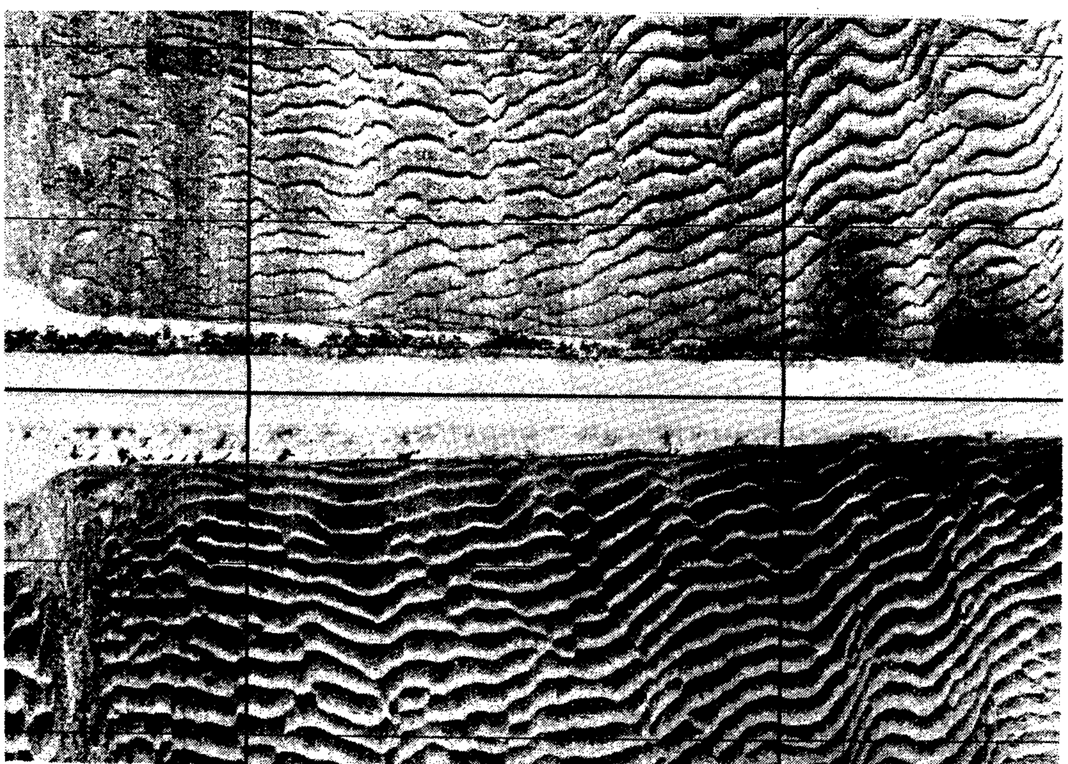


Figure C2. Side-scan return of S2 sand waves with wavelengths of six to twelve feet

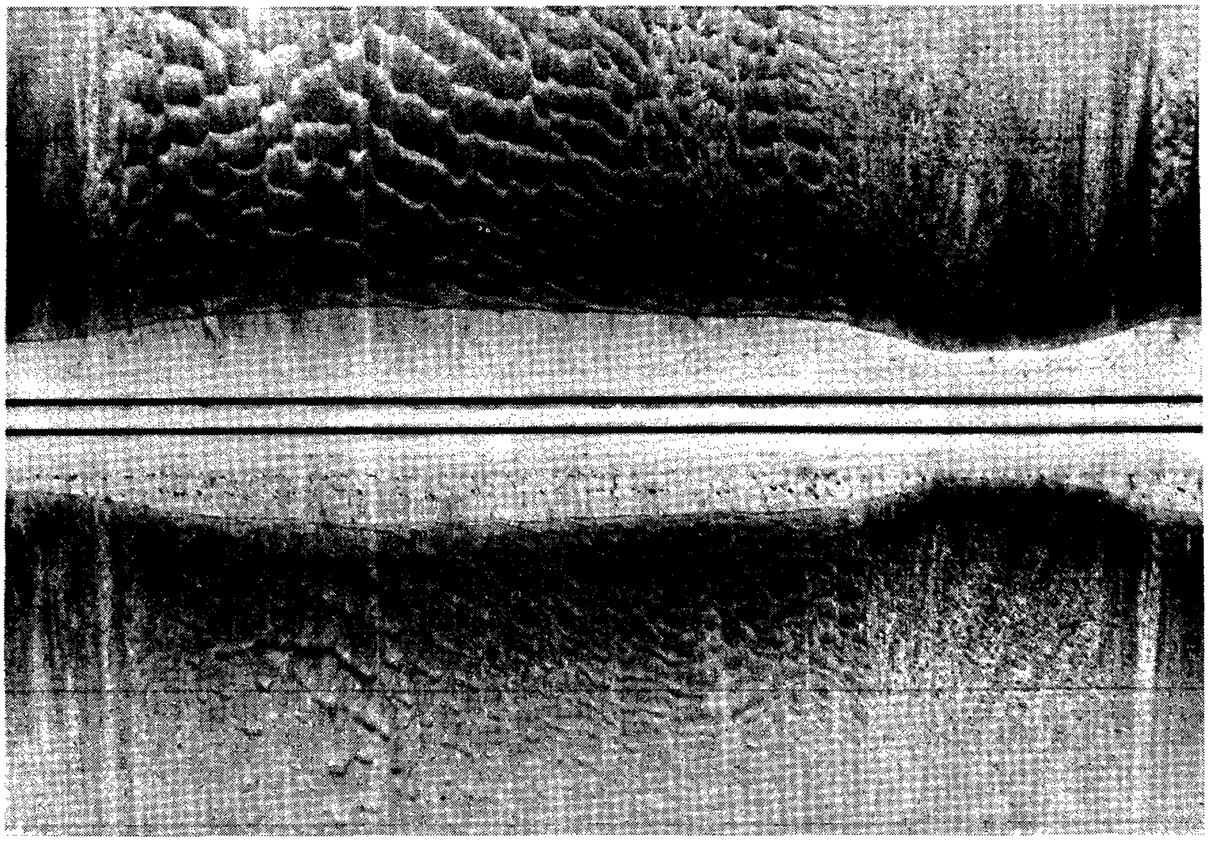


Figure C3. Side-scan return of S3 sand waves with wavelengths over twelve feet

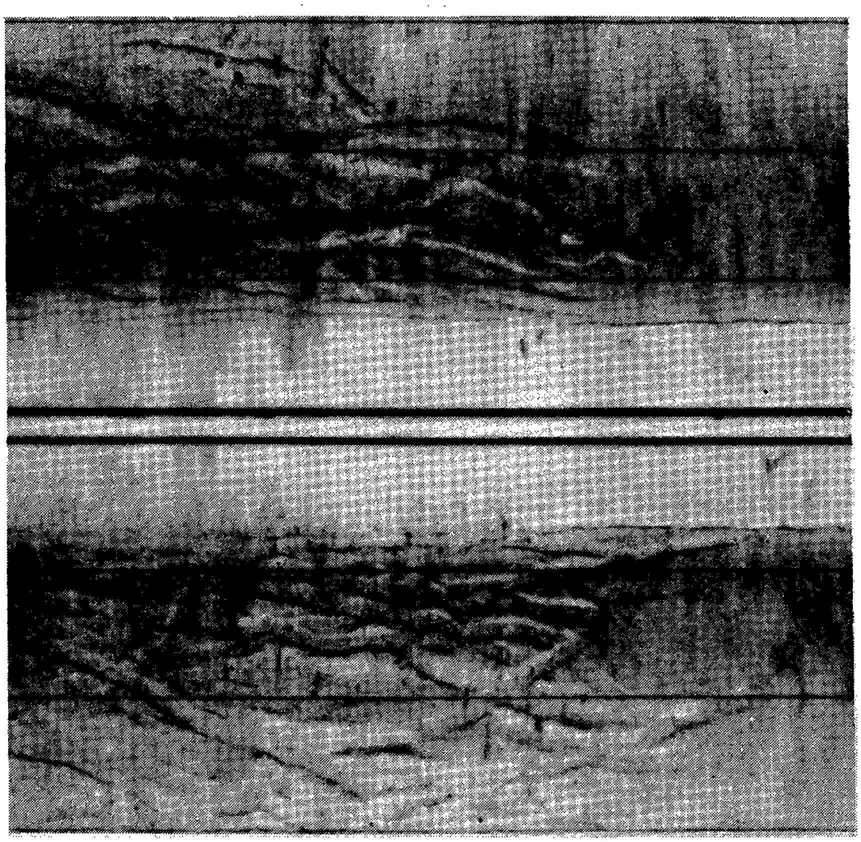


Figure C4. Side-scan return of dredger marks.

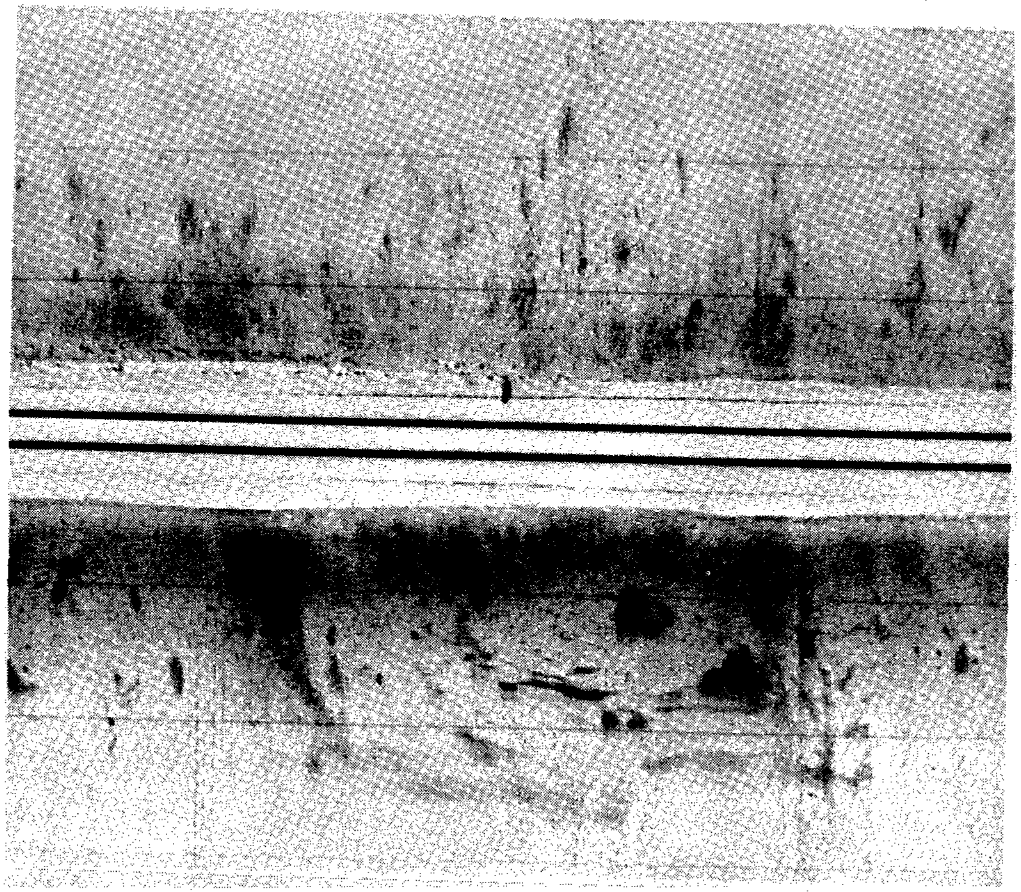


Figure C5. Side-scan return of mottled bottom

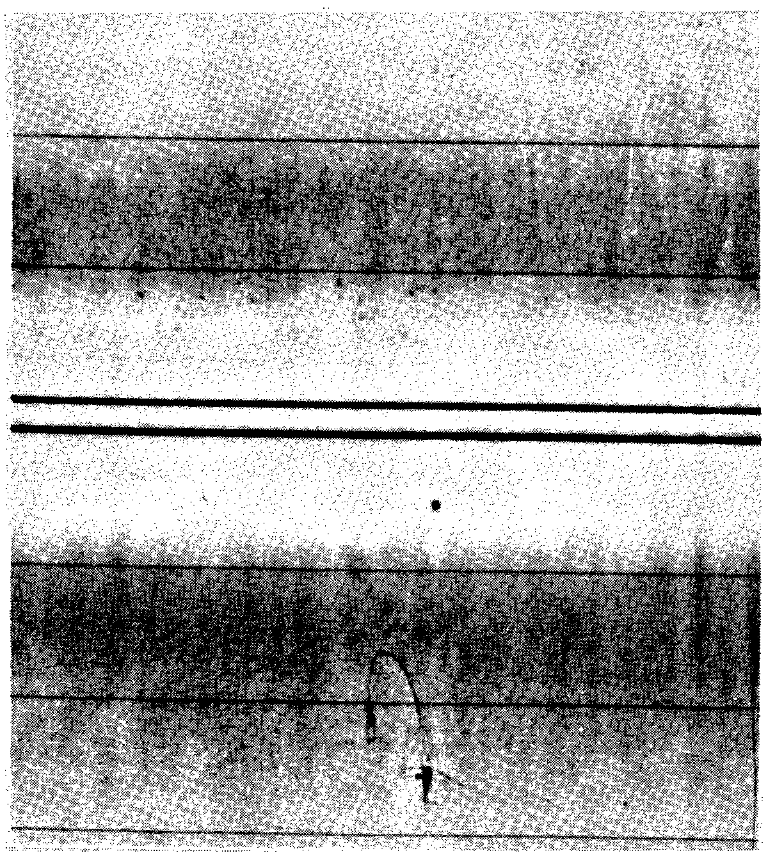


Figure C6. Side-scan return of buoy and anchor line

APPENDIX D

RESULTS OF PROBABILITY ANALYSIS FOR CHANNEL DEPTHS

TABLE D1
STATISTICAL QUANTITIES FOR JANUARY 1989
Datum: MLW

	REACH				
Quantity	1	2	3	4	5
Sample Size	3988	3364	2575	3754	3505
Average (ft)	51.4	51.4	50.6	50.8	51.7
St. Dev. (ft)	1.51	1.34	1.51	1.50	1.99
Skewness	0.555	0.183	-1.297	0.00996	-1.232
Kurtosis	-0.392	4.971	3.602	2.429	11.404
Skewness .025 confidence interval	0.00775	0.00845	0.00965	0.00800	0.00827
Kurtosis .025 confidence interval	0.155	0.169	0.193	0.160	0.165
Min. Depth	48.1	45.2	40.9	39.3	35.9
Station	6343	36365	26643	20036	12241
Range	1128	960	769	613	1427
Max. Depth	55.7	63.1	58.6	56.8	58.5
Station	22630	41374	24651	17574	8645
Range	755	1121	786	1320	991

TABLE D2
STATISTICAL QUANTITIES FOR MARCH 1989
Datum: MLW

	REACH				
Quantity	1	2	3	4	5
Sample Size	3220	2765	2035	3554	2623
Average (ft)	51.7	51.8	50.5	51.3	51.5
St. Dev. (ft)	1.56	1.53	1.68	1.55	2.16
Skewness	0.581	1.756	-1.393	-0.00776	-2.194
Kurtosis	-0.303	11.474	3.352	1.550	17.730
Skewness .025 confidence interval	0.00863	0.00932	0.108	0.00822	0.00956
Kurtosis .025 confidence interval	0.172	0.186	0.217	0.164	0.191
Min. Depth	48.3	46.3	40.4	40.8	31.2
Station	6912	30728	28425	18242	12192
Range	921	776	990	1395	1522
Max. Depth	56.8	68.9	55.8	57.1	58.4
Station	24978	41310	29155	16531	8630
Range	787	1122	898	1124	987

TABLE D3
STATISTICAL QUANTITIES FOR MAY 1989
Datum: MLW

REACH

Quantity	1	2	3	4	5
Sample Size	4391	3120	1991	3915	4220
Average (ft)	52.5	51.4	49.7	50.8	51.1
St. Dev. (ft)	1.45	1.29	1.27	1.57	2.17
Skewness	0.720	0.680	-1.019	-0.103	-1.778
Kurtosis	-0.246	2.331	2.286	1.083	12.081
Skewness .025 confidence interval	0.00739	0.00877	0.110	0.00783	0.00754
Kurtosis .025 confidence interval	0.148	0.175	0.220	0.156	0.151
Min. Depth	49.2	45.9	42.5	41.4	33.0
Station	1680	38011	24633	18228	12226
Range	921	754	754	1392	1528
Max. Depth	56.8	59.1	54.6	56.9	57.4
Station	24882	41327	28856	17631	8330
Range	1162	904	967	1294	1109

TABLE D4
STATISTICAL QUANTITIES FOR JUNE 1989
Datum: MLW

Quantity	REACH 1	2	3	4	5
Sample Size	3336	2813	1850	3228	3061
Average (ft)	52.1	52.0	51.2	52.4	52.4
St. Dev. (ft)	1.50	1.38	1.59	1.95	2.90
Skewness	0.506	1.095	0.150	-1.487	-0.959
Kurtosis	-0.520	4.418	1.911	20.087	5.696
Skewness .025 confidence interval	0.00848	0.00924	0.114	0.00862	0.00885
Kurtosis .025 confidence interval	0.170	0.185	0.228	0.172	0.177
Min. Depth	48.6	48.0	42.8	25.6	33.7
Station	7473	31021	23441	19237	12249
Range	923	752	1246	1197	1547
Max. Depth	56.2	64.8	58.4	58.2	61.9
Station	24924	41357	23154	16636	8620
Range	940	1107	904	1197	978

TABLE D5
STATISTICAL QUANTITIES FOR SEPTEMBER 1989
Datum: MLW

Quantity	REACH 1	REACH 2	REACH 3	REACH 4	REACH 5
Sample Size	3392	4526	2690	4900	1986
Average (ft)	51.7	52.1	50.9	51.8	50.7
St. Dev. (ft)	1.44	1.56	1.71	1.45	2.68
Skewness	0.515	0.766	0.148	-0.247	-2.795
Kurtosis	-0.145	3.040	0.613	2.956	11.735
Skewness .025 confidence interval	0.00841	0.00728	0.00944	0.00700	0.110
Kurtosis .025 confidence interval	0.168	0.145	0.189	0.140	0.220
Min. Depth	47.1	45.1	43.2	41.2	32.1
Station	10833	30964	26446	18430	12250
Range	754	760	756	1384	1531
Max. Depth	56.6	65.3	58.4	58.8	56.9
Station	23823	41450	23833	16622	12681
Range	922	1116	1047	1297	1311

TABLE D6
STATISTICAL QUANTITIES FOR OCTOBER 1989
Datum: MLW

	REACH				
Quantity	1	2	3	4	5
Sample Size	2782	3173	2345	3570	1714
Average (ft)	51.6	50.1	48.4	50.5	50.4
St. Dev. (ft)	1.62	1.31	1.85	1.79	2.76
Skewness	0.415	0.315	-0.00702	0.247	-1.435
Kurtosis	-0.267	1.134	-0.00599	0.631	5.015
Skewness .025 confidence interval	0.00929	0.00870	0.101	0.00820	0.118
Kurtosis .025 confidence interval	0.186	0.174	0.202	0.164	0.237
Min. Depth	46.8	46.0	37.6	42.5	34.6
Station	8718	32444	23449	18231	12226
Range	935	1206	1245	1398	1524
Max. Depth	57.2	58.6	54.6	58.3	57.2
Station	23810	48831	24454	16650	13060
Range	1126	1099	1037	1319	1024

TABLE D7
STATISTICAL QUANTITIES FOR JANUARY 1990
Datum: MLW

	REACH				
Quantity	1	2	3	4	5
Sample Size	3241	2555	1630	3350	1488
Average (ft)	52.1	51.3	51.1	50.9	51.2
St. Dev. (ft)	1.99	3.70	4.10	3.88	4.76
Skewness	0.0933	-0.0609	0.0954	-0.280	-1.770
Kurtosis	-0.695	-1.389	-1.157	-0.449	4.051
Skewness .025 confidence interval	0.0860	0.0969	0.121	0.0846	0.127
Kurtosis .025 confidence interval	0.172	0.194	0.243	0.169	0.254
Min. Depth	45.6	43.3	39.0	26.6	27.0
Station	114	47781	25854	19629	12264
Range	800	764	765	735	1544
Max. Depth	57.8	64.1	64.0	62.3	58.7
Station	685	46784	23441	22857	13042
Range	1198	1124	862	782	1103

TABLE D8
STATISTICAL QUANTITIES FOR JUNE 1990
Datum: MLW

REACH

Quantity	1	2	3	4	5
Sample Size	3347	2688	2018	3432	1830
Average (ft)	52.3	52.0	49.6	50.7	50.0
St. Dev. (ft)	1.60	1.61	1.53	1.75	2.92
Skewness	0.604	-0.0567	-0.468	-1.524	-2.450
Kurtosis	-0.107	2.910	0.271	6.926	7.678
Skewness .025 confidence interval	0.0847	0.0945	0.109	0.0836	0.114
Kurtosis .025 confidence interval	0.169	0.189	0.218	0.167	0.229
Min. Depth	47.9	42.8	41.5	37.1	33.2
Station	1317	38674	24036	18661	12272
Range	779	759	760	1378	1528
Max. Depth	57.4	65.0	53.2	55.6	55.0
Station	20663	49244	23355	16527	13241
Range	929	924	915	1292	1134

APPENDIX E
HISTOGRAMS OF DEPTH FOR EACH SURVEY

TABLE E1
HISTOGRAM OF DEPTHS FOR JANUARY 1989

DEPTH (ft)	REACH 1	REACH 2	REACH 3	REACH 4	REACH 5
36	0	0	0	0	8
37	0	0	0	0	1
38	0	0	0	0	1
39	0	0	0	1	1
40	0	0	0	0	1
41	0	0	2	0	1
42	0	0	1	1	3
43	0	0	4	0	6
44	0	0	0	2	4
45	0	4	7	3	0
46	0	23	15	10	8
47	0	4	118	36	8
48	13	32	126	166	28
49	294	109	119	375	181
50	921	576	476	1057	549
51	1140	1176	1029	1125	880
52	695	857	558	590	856
53	422	414	101	221	514
54	369	118	13	96	227
55	127	35	4	52	104
56	7	12	1	17	69
57	0	1	0	2	40
58	0	1	0	0	14
59	0	0	1	0	1

TABLE E2
HISTOGRAM OF DEPTHS FOR MARCH 1989

DEPTH (ft)	REACH 1	REACH 2	REACH 3	REACH 4	REACH 5
31	0	0	0	0	1
32	0	0	0	0	1
33	0	0	0	0	4
34	0	0	0	0	0
35	0	0	0	0	0
36	0	0	0	0	2
37	0	0	0	0	0
38	0	0	0	0	0
39	0	0	0	0	0
40	0	0	1	0	3
41	0	0	2	1	3
42	0	0	3	0	5
43	0	0	2	1	2
44	0	0	4	0	8
45	0	0	5	3	6
46	0	1	40	8	7
47	0	1	109	26	10
48	6	4	102	107	34
49	148	100	85	190	136
50	593	357	435	667	410
51	945	822	737	1045	675
52	657	783	393	803	630
53	346	358	100	443	365
54	306	206	16	164	167
55	187	82	0	70	67
56	31	33	1	23	57
57	1	9	0	3	27
58	0	0	0	0	3
59	0	2	0	0	0
60	0	2	0	0	0
61	0	1	0	0	0
62	0	1	0	0	0
63	0	1	0	0	0
64	0	0	0	0	0
65	0	0	0	0	0
66	0	0	0	0	0
67	0	1	0	0	0
68	0	0	0	0	0
69	0	1	0	0	0

TABLE E3
HISTOGRAM OF DEPTHS FOR MAY 1989

DEPTH (ft)	REACH 1	REACH 2	REACH 3	REACH 4	REACH 5
33	0	0	0	0	3
34	0	0	0	0	3
35	0	0	0	0	1
36	0	0	0	0	1
37	0	0	0	0	1
38	0	0	0	0	2
39	0	0	0	0	5
40	0	0	0	0	9
41	0	0	0	1	18
42	0	0	1	0	5
43	0	0	1	2	4
44	0	0	5	1	8
45	0	0	6	6	5
46	0	5	20	9	3
47	0	1	90	46	19
48	0	13	183	193	100
49	3	117	363	443	423
50	152	486	769	857	863
51	1081	1169	475	1092	1185
52	1397	791	69	736	751
53	798	337	7	342	372
54	368	113	1	136	222
55	400	68	1	37	120
56	191	13	0	11	83
57	1	3	0	3	14
58	0	1	0	0	0
59	0	3	0	0	0

TABLE E4
HISTOGRAM OF DEPTHS FOR JUNE 1989

DEPTH (ft)	REACH 1	REACH 2	REACH 3	REACH 4	REACH 5
26	0	0	0	2	0
27	0	0	0	0	0
28	0	0	0	0	0
29	0	0	0	0	0
30	0	0	0	0	0
31	0	0	0	0	0
32	0	0	0	0	0
33	0	0	0	0	0
34	0	0	0	0	2
35	0	0	0	0	5
36	0	0	0	0	0
37	0	0	0	0	1
38	0	0	0	0	0
39	0	0	0	0	5
40	0	0	0	0	5
41	0	0	0	0	9
42	0	0	0	0	11
43	0	0	1	0	15
44	0	0	2	0	8
45	0	0	0	3	3
46	0	0	7	3	8
47	0	0	22	7	3
48	0	3	30	13	17
49	41	55	136	124	102
50	415	250	424	373	403
51	911	758	520	559	559
52	851	959	386	599	537
53	478	454	186	611	362
54	307	192	94	512	347
55	313	83	27	264	282
56	20	46	8	128	164
57	0	7	2	25	104
58	0	3	5	5	49
59	0	0	0	0	30
60	0	2	0	0	21
61	0	0	0	0	6
62	0	0	0	0	3
63	0	0	0	0	0
64	0	0	0	0	0
65	0	1	0	0	0

TABLE E5
HISTOGRAM OF DEPTHS FOR SEPTEMBER 1989

DEPTH (ft)	REACH 1	REACH 2	REACH 3	REACH 4	REACH 5
32	0	0	0	0	3
33	0	0	0	0	1
34	0	0	0	0	0
35	0	0	0	0	3
36	0	0	0	0	1
37	0	0	0	0	1
38	0	0	0	0	1
39	0	0	0	0	8
40	0	0	0	0	10
41	0	0	0	2	17
42	0	0	0	0	9
43	0	0	1	1	15
44	0	0	1	1	10
45	0	1	3	3	11
46	0	1	15	11	13
47	1	0	43	17	9
48	7	21	111	43	26
49	114	115	360	155	103
50	629	511	591	505	333
51	946	1085	649	1294	555
52	814	1203	465	1496	404
53	452	845	281	873	276
54	273	443	104	334	143
55	137	196	48	109	28
56	18	77	12	41	3
57	1	17	5	14	3
58	0	3	1	0	0
59	0	0	0	1	0
60	0	4	0	0	0
61	0	0	0	0	0
62	0	1	0	0	0
63	0	1	0	0	0
64	0	1	0	0	0
65	0	1	0	0	0

TABLE E6
HISTOGRAM OF DEPTHS FOR OCTOBER 1989

DEPTH (ft)	REACH 1	REACH 2	REACH 3	REACH 4	REACH 5
36	0	0	0	0	1
37	0	0	0	0	1
38	0	0	1	0	3
39	0	0	0	0	5
40	0	0	0	0	7
41	0	0	0	0	10
42	0	0	1	0	11
43	0	0	0	4	6
44	0	0	6	3	7
45	0	0	118	7	9
46	0	9	302	25	8
47	3	68	300	69	52
48	31	211	418	276	181
49	189	769	439	759	303
50	541	981	473	753	226
51	739	717	188	675	236
52	534	300	71	533	274
53	342	87	19	279	212
54	259	25	8	112	102
55	120	2	1	52	39
56	21	3	0	18	12
57	3	0	0	4	5
58	0	0	0	1	0
59	0	1	0	0	0

TABLE E7
HISTOGRAM OF DEPTHS FOR JANUARY 1990

DEPTH (ft)	REACH 1	REACH 2	REACH 3	REACH 4	REACH 5
27	0	0	0	1	1
28	0	0	0	0	2
29	0	0	0	0	3
30	0	0	0	0	1
31	0	0	0	0	3
32	0	0	0	0	2
33	0	0	0	0	4
34	0	0	0	1	5
35	0	0	0	0	7
36	0	0	0	0	6
37	0	0	0	0	4
38	0	0	0	1	4
39	0	0	1	5	5
40	0	0	0	1	2
41	0	0	1	4	3
42	0	0	1	7	7
43	0	1	16	29	19
44	0	15	23	89	31
45	0	60	38	145	54
46	1	143	113	222	76
47	3	316	198	292	77
48	70	319	191	313	72
49	260	231	164	245	54
50	454	117	101	200	34
51	549	53	31	137	52
52	552	56	28	184	88
53	510	168	77	331	228
54	428	407	168	450	319
55	292	371	192	356	195
56	92	183	152	194	101
57	28	84	76	94	26
58	2	22	32	30	2
59	0	7	13	14	1
60	0	1	10	2	0
61	0	0	2	2	0
62	0	0	0	1	0
63	0	0	1	0	0
64	0	1	1	0	0

TABLE E8
HISTOGRAM OF DEPTHS FOR JUNE 1990

DEPTH (ft)	REACH 1	REACH 2	REACH 3	REACH 4	REACH 5
33	0	0	0	0	2
34	0	0	0	0	0
35	0	0	0	0	3
36	0	0	0	0	3
37	0	0	0	1	7
38	0	0	0	2	12
39	0	0	0	3	13
40	0	0	0	1	7
41	0	0	0	2	11
42	0	0	1	6	18
43	0	1	1	3	14
44	0	4	3	8	20
45	0	2	7	25	16
46	0	3	48	35	14
47	0	6	118	52	19
48	3	19	306	135	77
49	34	83	409	344	236
50	300	309	487	702	426
51	800	567	441	1026	434
52	900	696	175	744	298
53	594	552	22	232	152
54	284	301	0	85	39
55	271	99	0	24	9
56	139	41	0	2	0
57	22	4	0	0	0
58	0	0	0	0	0
59	0	0	0	0	0
60	0	0	0	0	0
61	0	0	0	0	0
62	0	0	0	0	0
63	0	0	0	0	0
64	0	0	0	0	0
65	0	1	0	0	0

APPENDIX F
99 PERCENT CONTROLLING DEPTHS
REACH-BY-REACH

TABLE F1
99 PERCENT CONTROL DEPTHS FOR SEPTEMBER, 1989
Datum: MLW

REACH 1

99TH PERCENTILE DEPTH 48.3 feet

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
48.2	8901	1131
48.2	6201	1126
48.3	3458	937
48.1	5940	932
47.9	6062	926
48.3	6075	924
47.1	6138	921
48.1	6256	909
47.8	6583	911
47.7	6594	912
47.1	7071	914
48.0	8376	935
46.8	8719	936
48.3	8981	940
48.1	9897	933
48.0	14411	923
48.2	14884	926
48.1	15160	930
47.6	15656	927

REACH 2

99TH PERCENTILE DEPTH 46.8 feet

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
46.8	32701	1192
46.8	32687	1194
46.8	32679	1196
46.8	32658	1198
46.5	32626	1198
46.4	32612	1199
46.5	32599	1200
46.7	32548	1204
46.3	32536	1204

DEPTH	STATION	RANGE
46.4	32524	1204
46.8	32511	1205
46.8	32482	1208
46.4	32461	1207
46.0	32444	1207
46.7	32422	1210
46.8	32408	1211
46.6	32395	1214
46.6	32381	1213
46.4	32358	1217
46.2	32344	1216
46.5	32329	1218
46.7	32305	1217
46.6	32257	1217
46.6	32229	1218
46.7	32224	1218
46.7	30567	1102
46.5	30555	1101
46.8	30544	1103
46.7	30501	1108

REACH 3

99TH PERCENTILE DEPTH 44.6 feet

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
44.3	28340	1246
44.4	28336	1233
44.6	28418	1225
44.1	28417	1244
41.8	23858	753
44.0	23652	1248
37.6	23449	1246
43.6	28237	1223
44.4	28237	1113

REACH 4

99TH PERCENTILE DEPTH 46.4 feet

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
45.2	17412	1527
45.1	17409	1538
45.9	18238	1363
42.5	18232	1399
43.3	18424	1394
44.1	18423	1383
44.6	18627	1390

DEPTH	STATION	RANGE
45.0	19055	1384
44.8	19053	1397
45.5	20634	1397
44.1	21064	1392
45.4	21239	1386
46.3	21250	610
46.2	21447	610
45.4	21429	1376
46.3	21854	601
45.6	21837	1371
45.7	21838	1379
42.6	21835	1398
46.3	22016	1399
43.0	22476	602
44.3	22854	751
46.2	18381	1305
45.9	18394	1300
46.3	18408	1302
46.1	18425	1307
46.3	18438	1307
46.3	18456	1305
46.1	18472	1306
46.1	18509	1309
46.2	18538	1305

REACH 5

99TH PERCENTILE DEPTH 39.9 feet

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
38.8	12029	1366
38.6	12237	1438
38.8	12235	1447
36.3	12232	1458
35.0	12230	1487
35.3	12227	1497
34.8	12227	1516
34.6	12226	1524
39.9	12427	1414
39.5	12429	1393
38.0	11998	1337
37.5	12014	1334
38.3	12033	1334
38.1	12050	1336
38.7	12062	1335
39.1	12078	1334
39.9	12417	1307

TABLE F2

99 PERCENT CONTROL DEPTH FOR OCTOBER, 1989

Datum: MLW

REACH 1

99TH PERCENTILE DEPTH 48.3 feet

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
48.2	8901	1130
48.2	6201	1126
48.3	3458	937
48.1	5939	931
47.9	6061	926
48.3	6075	923
47.1	6138	921
48.1	6256	909
47.8	6583	911
47.7	6594	911
47.1	7071	914
47.9	8376	935
46.8	8718	936
48.3	8980	940
48.1	9896	933
48.0	14411	923
48.2	14884	925
48.1	15160	930
47.6	15656	926

REACH 2

99TH PERCENTILE DEPTH 46.8 feet

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
46.8	32701	1192
46.8	32687	1194
46.8	32678	1196
46.8	32626	1198
46.4	32612	1199
46.5	32599	1200
46.7	32548	1204
46.3	32535	1204
46.4	32524	1204
46.8	32511	1205
46.8	32481	1208
46.4	32461	1207
46.0	32444	1207
46.4	32434	1209
46.7	32422	1210

DEPTH	STATION	RANGE
46.8	32408	1211
46.6	32395	1213
46.6	32381	1213
46.2	32344	1215
46.5	32329	1218
46.7	32305	1217
46.6	32257	1217
46.5	32240	1217
46.6	32229	1218
46.7	32224	1218
46.7	30567	1101
46.5	30555	1101
46.8	30544	1101
46.7	30501	1108

REACH 3

99TH PERCENTILE DEPTH 44.6 feet

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
44.3	28340	1246
44.4	28336	1233
44.6	28418	1225
44.1	28417	1244
41.8	23858	754
44.0	23652	1248
43.6	28237	1223
44.4	28237	1113

REACH 4

99TH PERCENTILE DEPTH 46.4 feet

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
45.3	17412	1527
45.2	17409	1538
45.9	18238	1363
42.5	18231	1399
43.3	18424	1394
44.1	18423	1383
44.6	18627	1390
45.0	19055	1384
44.8	19053	1397
45.6	20634	1397
44.1	21064	1392
45.4	21239	1386
46.3	21250	610
46.2	21447	610
45.4	21429	1376

DEPTH	STATION	RANGE
46.3	21854	601
45.6	21837	1371
45.7	21838	1379
42.6	21836	1398
46.3	22016	1399
43.0	22476	602
44.3	22854	751
45.9	18394	1301
46.3	18408	1302
46.1	18425	1307
46.3	18438	1307
46.3	18456	1305
46.1	18472	1306
46.1	18509	1309
46.2	18538	1305

REACH 5

99TH PERCENTILE DEPTH 39.9 feet

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
38.8	12029	1366
38.6	12237	1439
38.8	12235	1447
36.3	12232	1459
35.0	12230	1487
35.3	12227	1497
34.8	12227	1516
34.6	12226	1524
39.9	12427	1414
39.5	12429	1393
38.0	11998	1337
38.3	12033	1334
38.1	12050	1336
38.7	12062	1335
39.1	12078	1334
39.9	12416	1307

TABLE F3

99 PERCENT CONTROL DEPTH FOR JANUARY, 1990

Datum: MLW

REACH 1

99TH PERCENTILE DEPTH 47.9

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
47.5	6115	913
47.7	6081	915
47.9	5968	910
47.8	5817	908
47.9	5714	921
47.6	1540	926
47.8	1524	926
47.5	4330	935
47.1	57	940
47.2	66	944
45.6	114	800
47.8	82	758

REACH 2

99TH PERCENTILE DEPTH 44.6

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
44.5	47504	934
44.6	48077	895
44.5	48437	908
44.4	48690	905
44.3	48707	903
44.3	48884	897
44.4	49922	917
44.4	48043	757
43.3	47780	763
43.5	47763	758
44.1	46804	751
43.7	40345	760
43.6	40336	762
44.6	40281	758
44.4	40254	752
44.6	33214	908
44.4	33279	909
44.6	33321	909
44.6	33626	914
44.4	34128	908

DEPTH	STATION	RANGE
44.6	34224	908
44.6	34720	910
44.1	37352	934

REACH 3

99TH PERCENTILE DEPTH 43.3

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
40.7	24832	1227
42.4	25450	925
42.8	25450	915
42.7	25428	765
42.8	25426	759
42.8	25631	871
42.8	25632	890
42.8	25639	946
43.1	25629	1006
42.7	25617	1039
43.2	25621	1065
43.3	25620	1240
39.0	25854	765
43.3	27829	1246
42.5	26225	752
43.0	24107	751

REACH 4

99TH PERCENTILE DEPTH 43.0

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
38.6	18446	1368
40.5	18857	1366
40.4	18858	1378
42.4	19053	605
42.6	19052	616
42.6	19033	1305
42.6	19034	1334
42.1	19035	1348
39.3	19036	1364
38.9	19035	1373
38.7	19038	1385
33.8	19039	1398
37.6	19244	1397
41.8	19243	1388
41.7	19239	1375
41.3	19438	1367

DEPTH	STATION	RANGE
41.4	19441	1383
39.2	19441	1395
42.5	19619	1392
26.6	19628	735
42.9	19848	1393
42.3	20246	1381
42.3	21044	1386
42.2	21439	1399
42.7	21668	1393
40.8	22237	1390
42.6	21511	714
42.7	21058	733
42.9	18796	714
42.5	17702	719
42.6	17694	719
42.7	17639	722

REACH 5

99TH PERCENTILE DEPTH 33.2

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
33.0	12459	1402
31.2	12256	1393
31.5	12257	1454
29.8	12259	1457
28.6	12261	1486
28.9	12258	1494
28.6	12258	1506
27.6	12262	1517
27.6	12266	1539
26.9	12264	1544
32.6	12056	1392
31.0	12056	1367
30.7	12062	1362
31.7	12064	1356
33.2	12064	1329

TABLE F4

99 PERCENT CONTROL DEPTH FOR JUNE, 1990
Datum: MLW

REACH 1

99TH PERCENTILE DEPTH 49.4

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
49.1	5850	921
49.0	5922	919
49.3	6050	929
48.6	6134	928
49.3	6209	931
49.3	7124	935
49.0	7271	929
49.3	8224	928
49.3	1440	925
49.3	1444	927
49.3	8737	1117
48.9	1017	928
47.8	1317	779
48.6	1313	785
48.1	1286	854
49.3	1110	1249
48.6	1489	878
49.3	1491	876
49.3	1516	826
49.2	1525	811
48.3	1550	754
48.6	1699	925
48.8	1695	929
48.6	1656	1035
49.0	2093	1038
49.2	2055	1147

REACH 2

99TH PERCENTILE DEPTH 48.1

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
48.0	32041	1249
47.4	31626	1245
48.0	31642	771
48.0	31245	1206
48.0	31244	1221
46.9	31243	1249

DEPTH	STATION	RANGE
46.8	30845	1247
46.6	30845	1239
47.5	30845	1219
47.8	30837	1205
47.1	30850	755
47.5	30651	1221
44.4	37585	752
43.8	38390	752
45.9	38623	755
42.7	38674	759
45.5	41522	753
45.4	42075	750
45.9	43328	754
44.1	43849	753
44.3	44028	752
44.7	44216	750
46.6	47910	751
48.0	48640	912

REACH 3

99TH PERCENTILE DEPTH 45.7

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
45.2	29259	1247
45.5	29262	1237
45.5	28830	1230
45.1	28430	1238
44.5	28047	1244
44.8	26838	763
44.9	23249	755
43.0	23250	751
44.0	23641	763
45.5	24034	764
41.5	24036	760
43.9	24430	755
45.6	28927	1236
45.2	28252	1244
45.2	27826	764
44.1	24955	751

REACH 4

99TH PERCENTILE DEPTH 44.8

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
44.6	17439	1525
42.1	17437	1545
44.7	18048	624
42.0	18261	1375
42.0	18261	1382
39.9	18261	1389
38.2	18263	1398
37.6	18455	1393
38.7	18452	1382
39.4	18450	1362
43.2	18452	1353
42.0	18451	1332
44.0	18457	1324
44.8	18668	1313
42.4	18668	1331
41.9	18662	1348
40.6	18659	1356
38.7	18661	1368
37.1	18661	1378
43.2	18846	1397
44.2	18837	1380
44.5	18847	616
43.7	18841	600
44.7	19438	1376
41.0	19433	1394
43.7	21039	1386
43.8	22451	601
42.6	22451	603
44.6	18610	1330
44.3	18603	1328
44.3	18589	1321
44.6	18579	1318
44.4	18447	1321

REACH 5

99TH PERCENTILE DEPTH 37.8

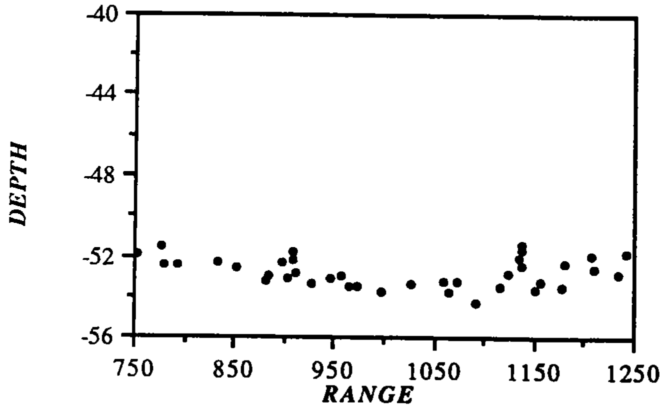
DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
37.7	12445	1503
37.2	12445	1481
37.5	12269	1306
36.6	12268	1394
37.7	12269	1428

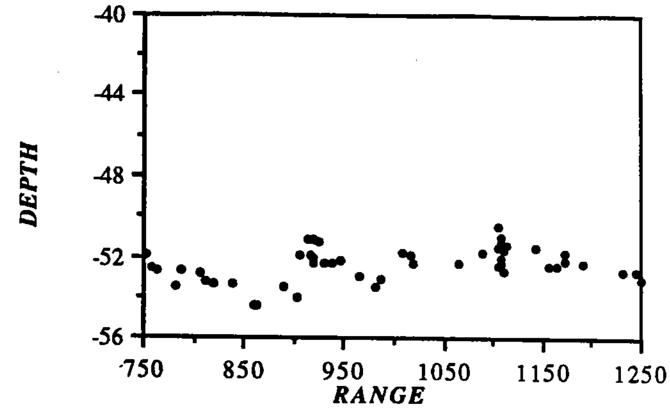
DEPTH	STATION	RANGE
34.7	12270	1450
37.1	12273	1486
36.8	12272	1495
35.2	12269	1498
33.1	12272	1528
33.3	12050	1386
34.6	12053	1370
37.4	12052	1366
36.4	12052	1389
35.6	12050	1382
36.3	12043	1368
37.2	12043	1364
37.3	12034	1343

APPENDIX G
RANGE VERSUS DEPTH (feet) FOR SELECTED CHANNEL LOCATIONS

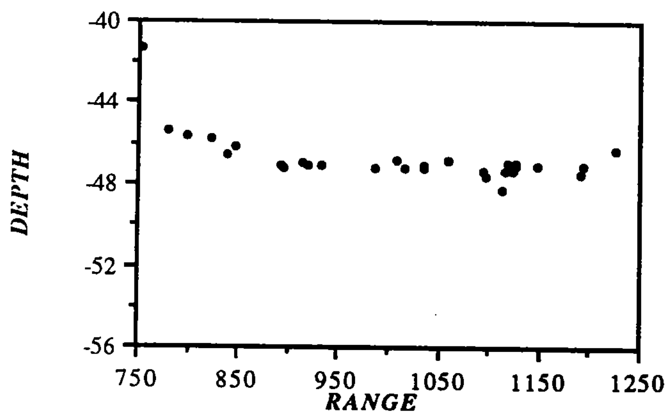
STATION 122+00



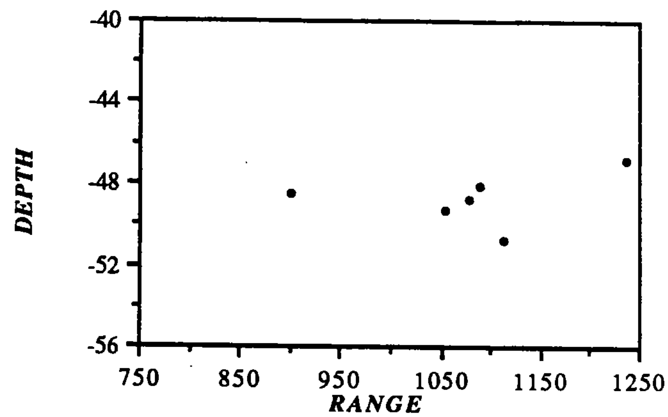
STATION 180+00



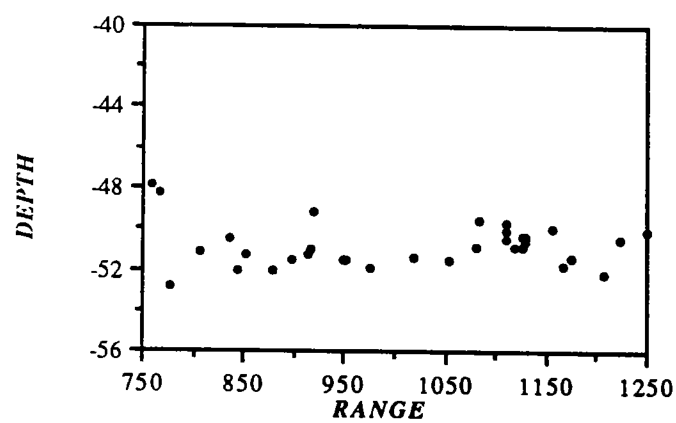
STATION 234+00



STATION 238+00



STATION 282+00



STATION 284+00

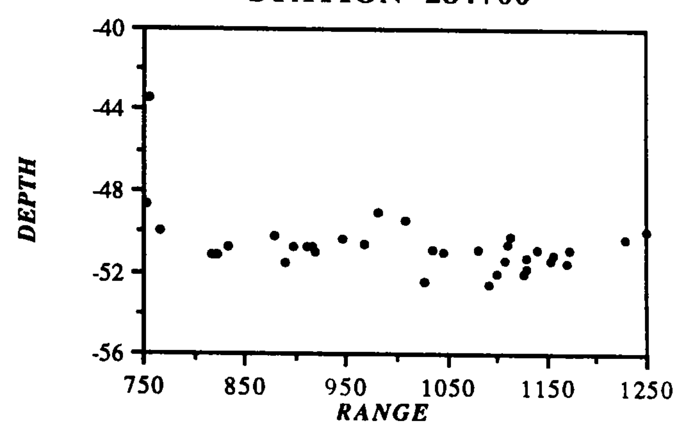


Figure G1. Range versus Depth (feet) for January, 1989

Datum: MLW

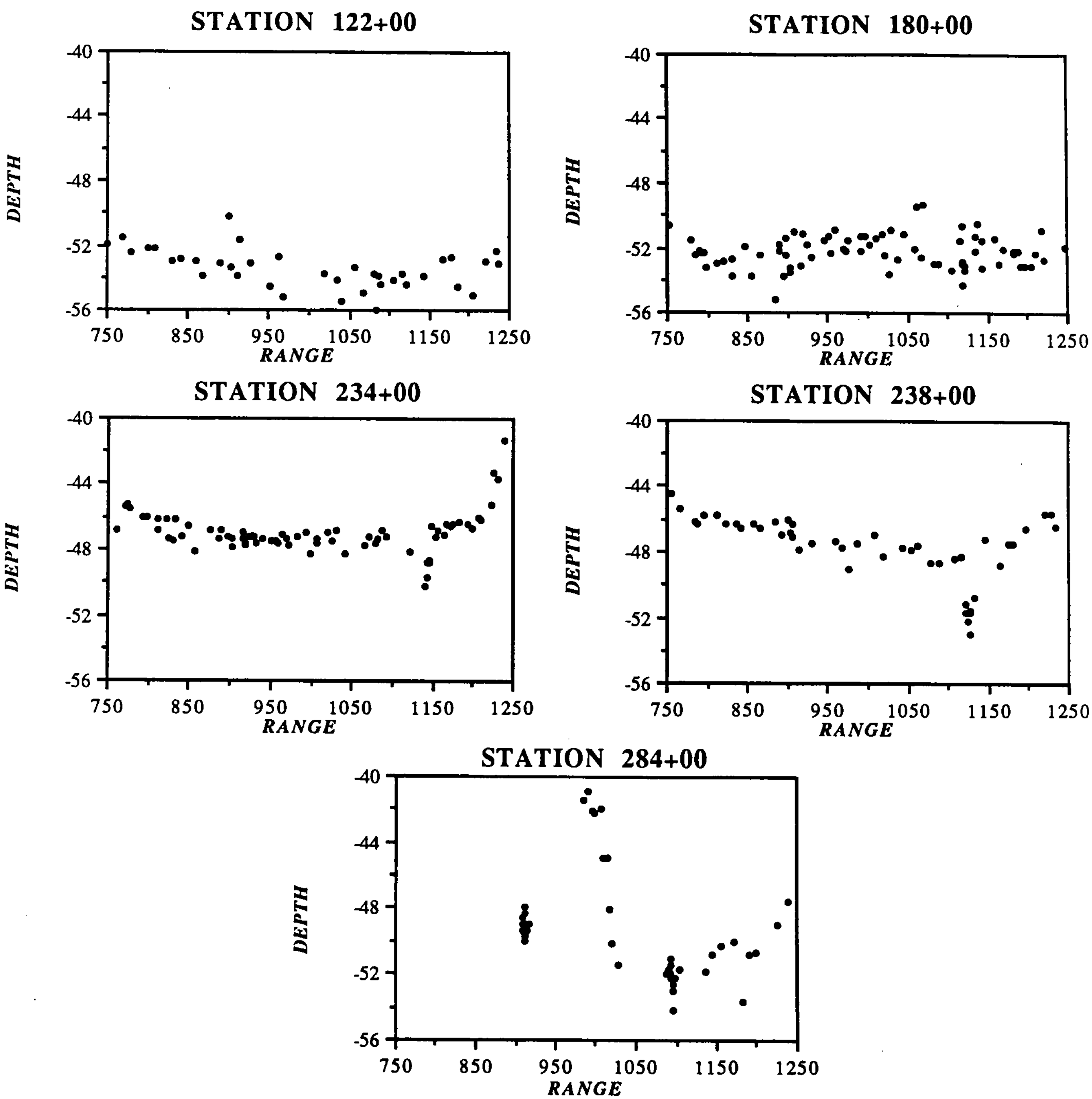


Figure G2. Range versus Depth (feet) for March, 1989

Datum: MLW

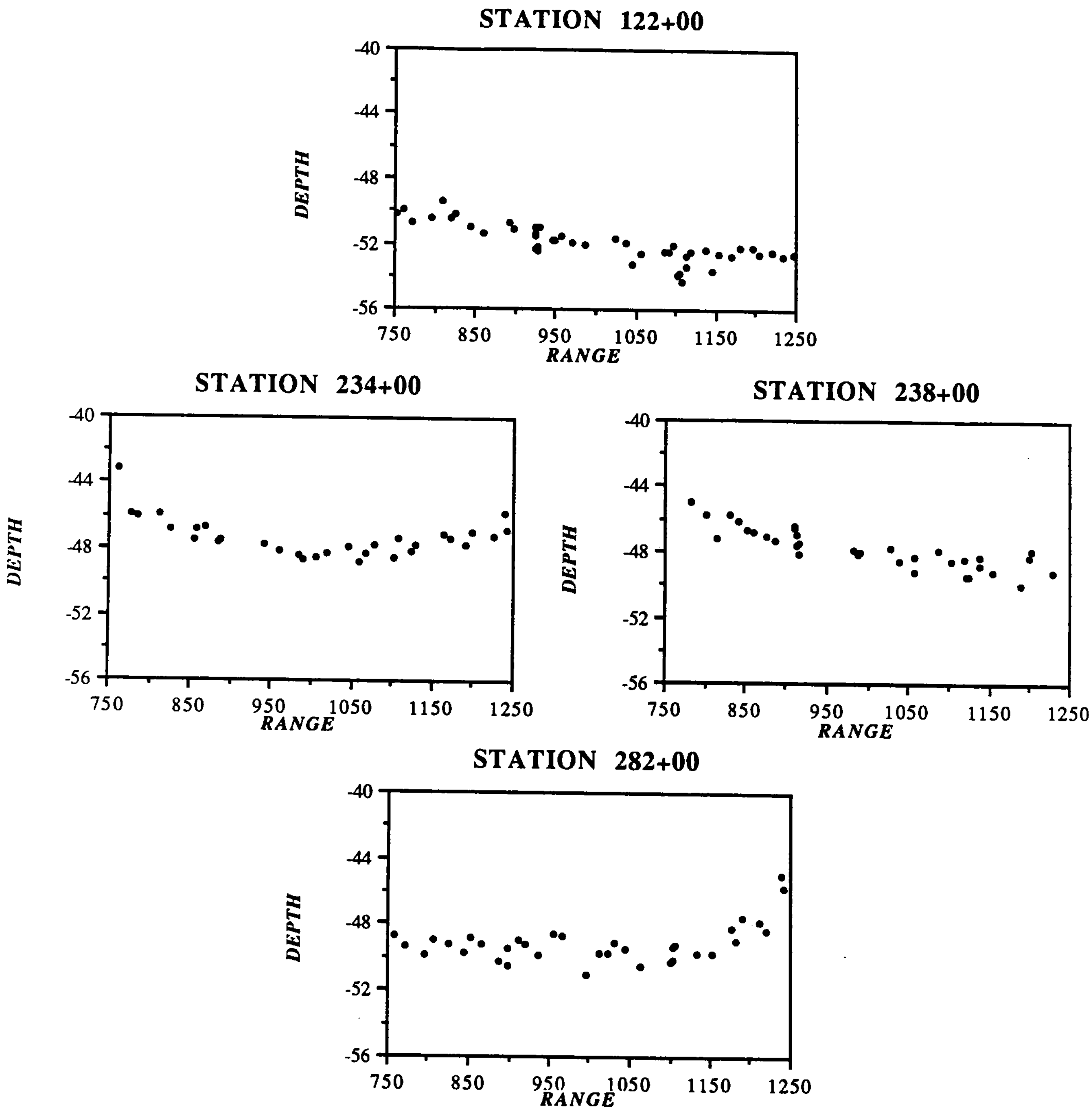


Figure G3. Range versus Depth (feet) for May, 1989

Datum: MLW

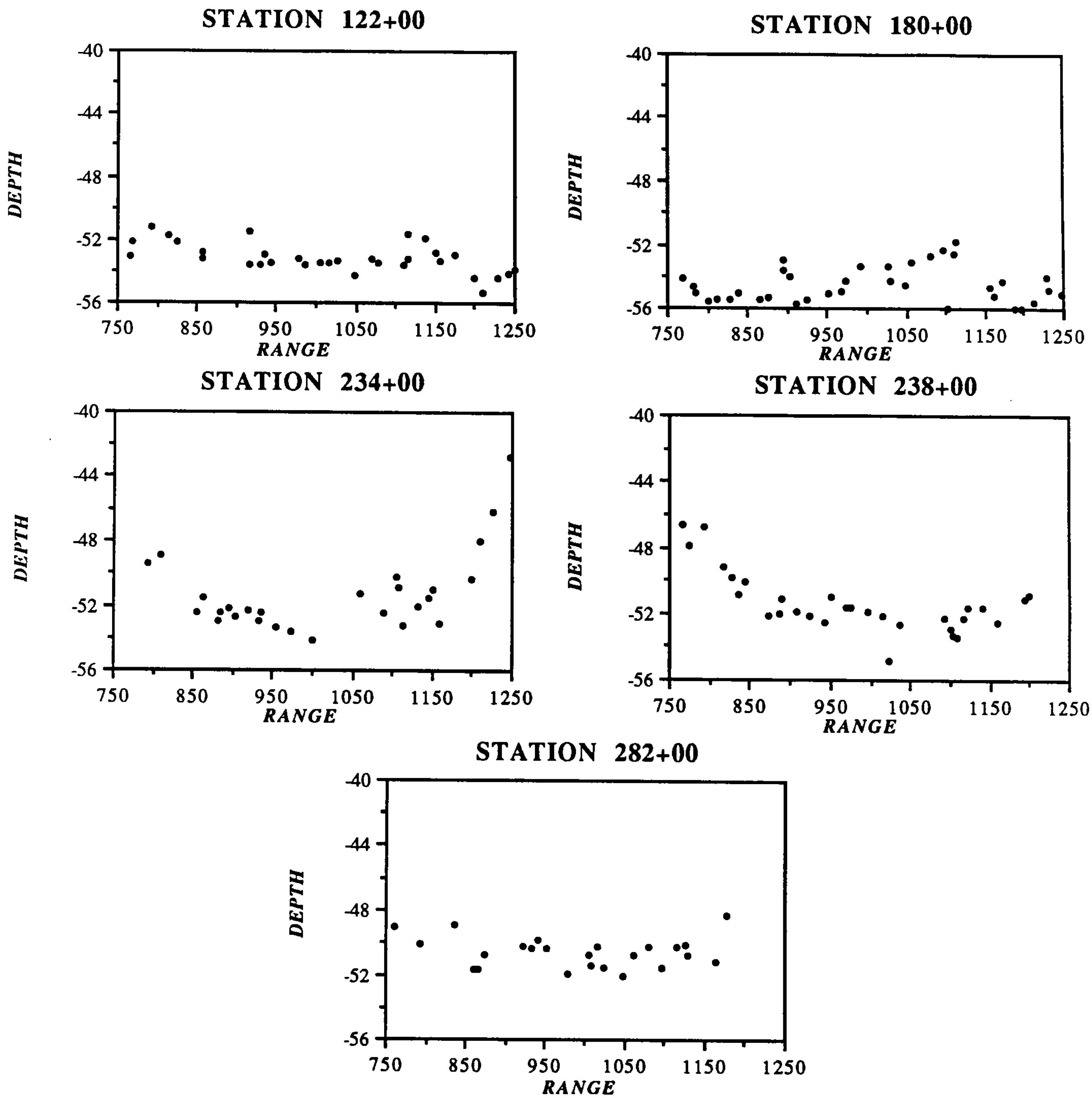


Figure G4. Range versus Depth (feet) for June, 1989

Datum: MLW

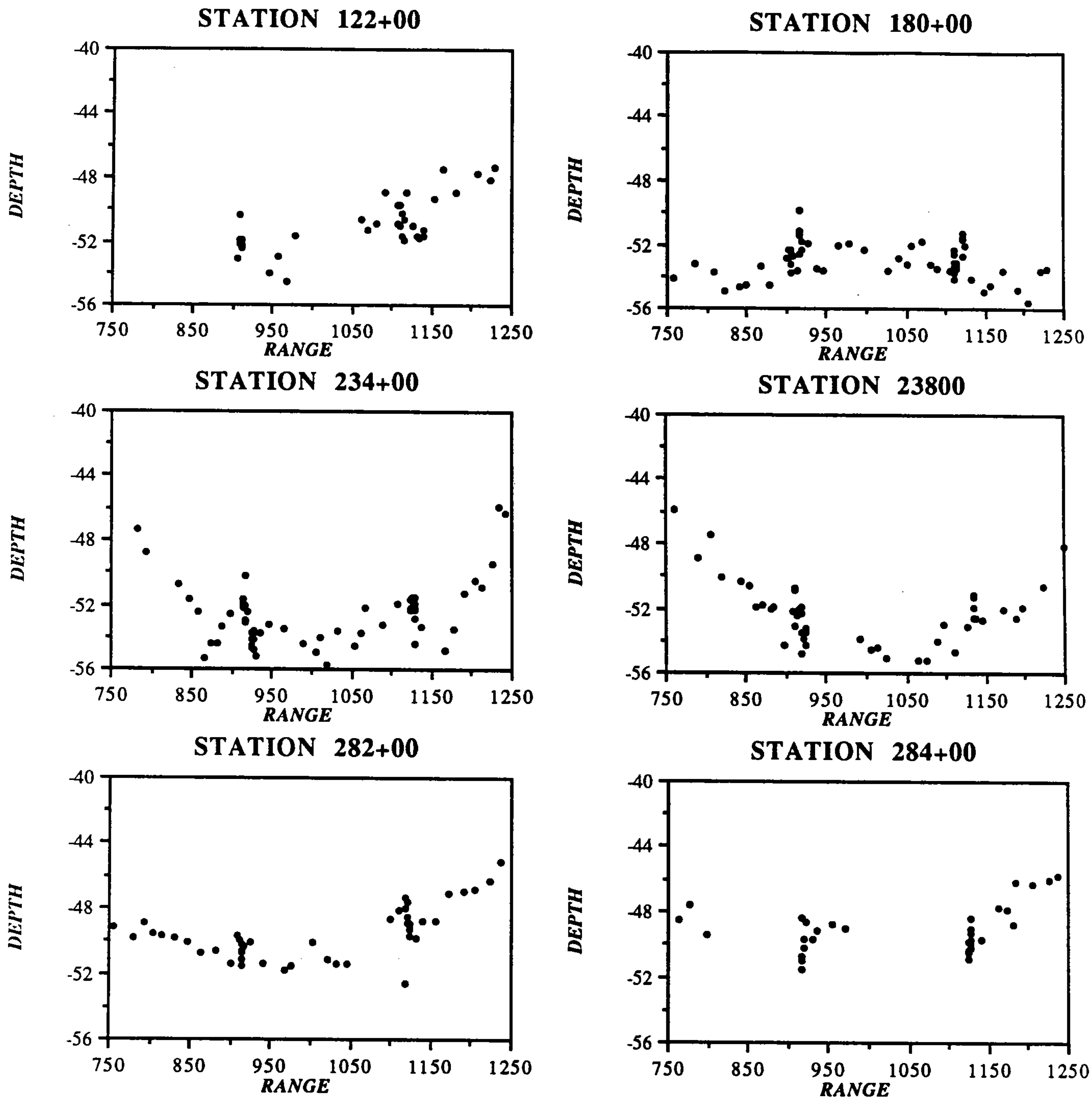


Figure G5. Range versus Depth (feet) for September, 1989

Datum: MLW

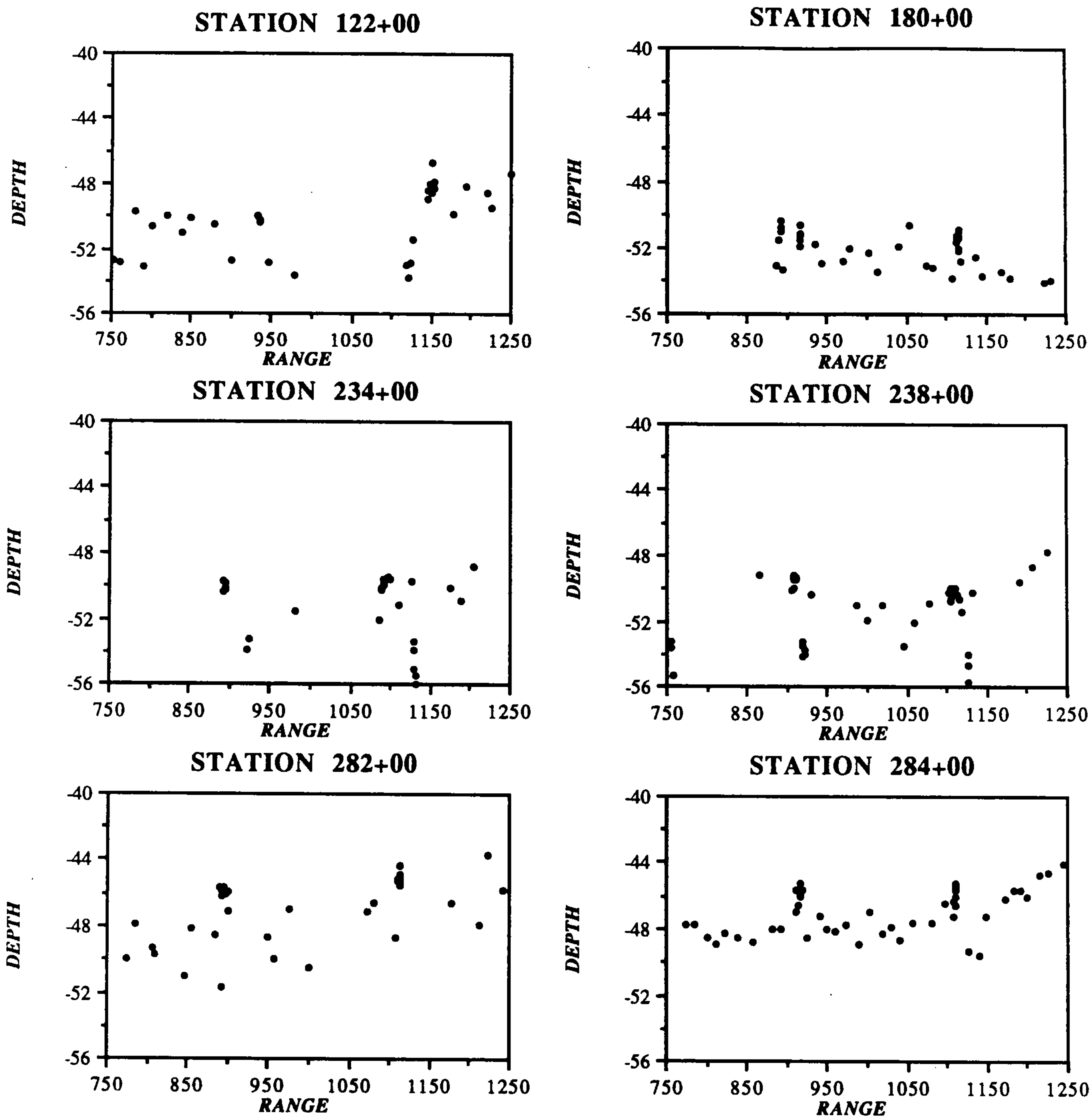


Figure G6. Range versus Depth (feet) for October, 1989

Datum: MLW

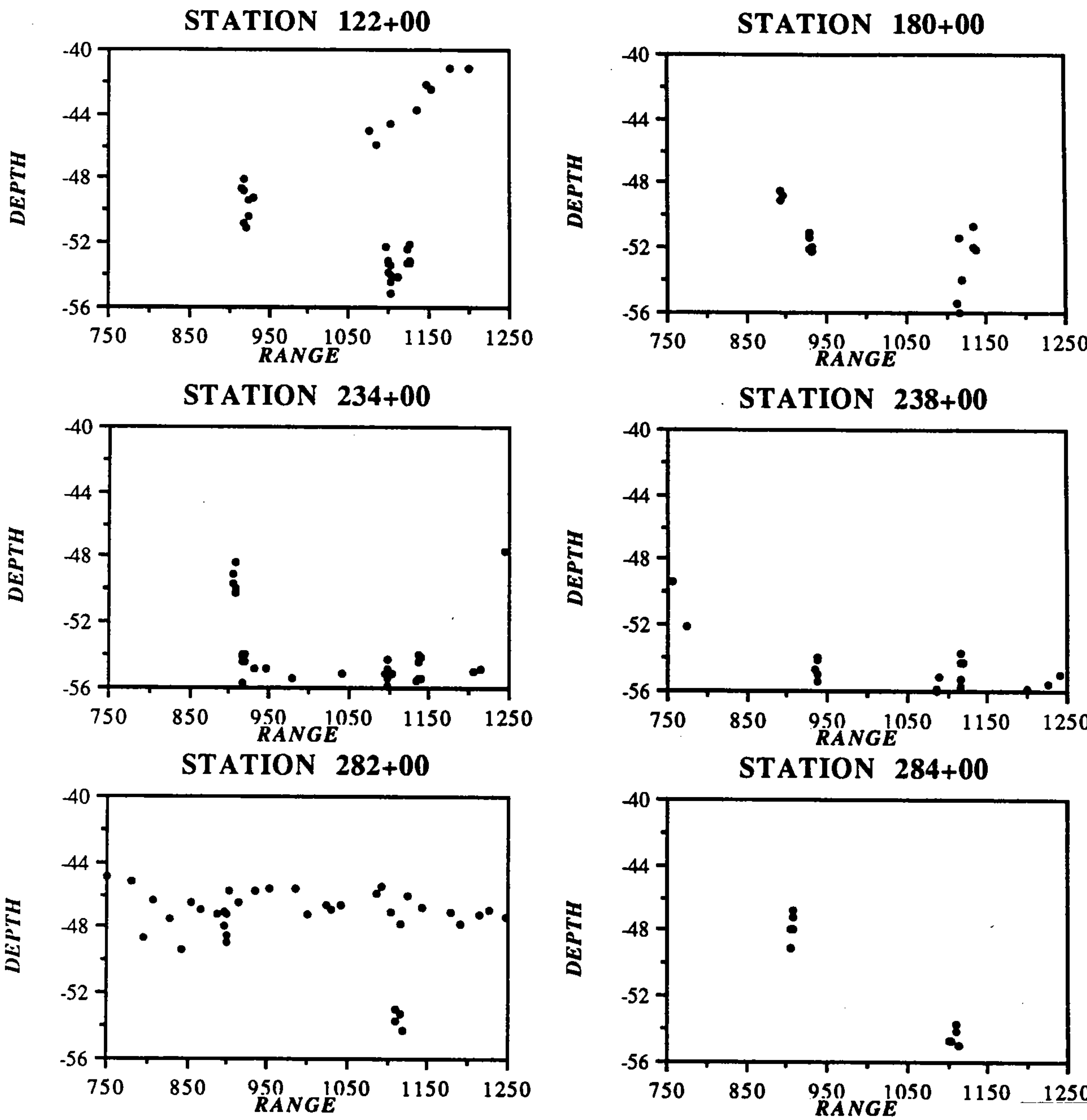


Figure G7. Range versus Depth (feet) for January, 1990

Datum: MLW

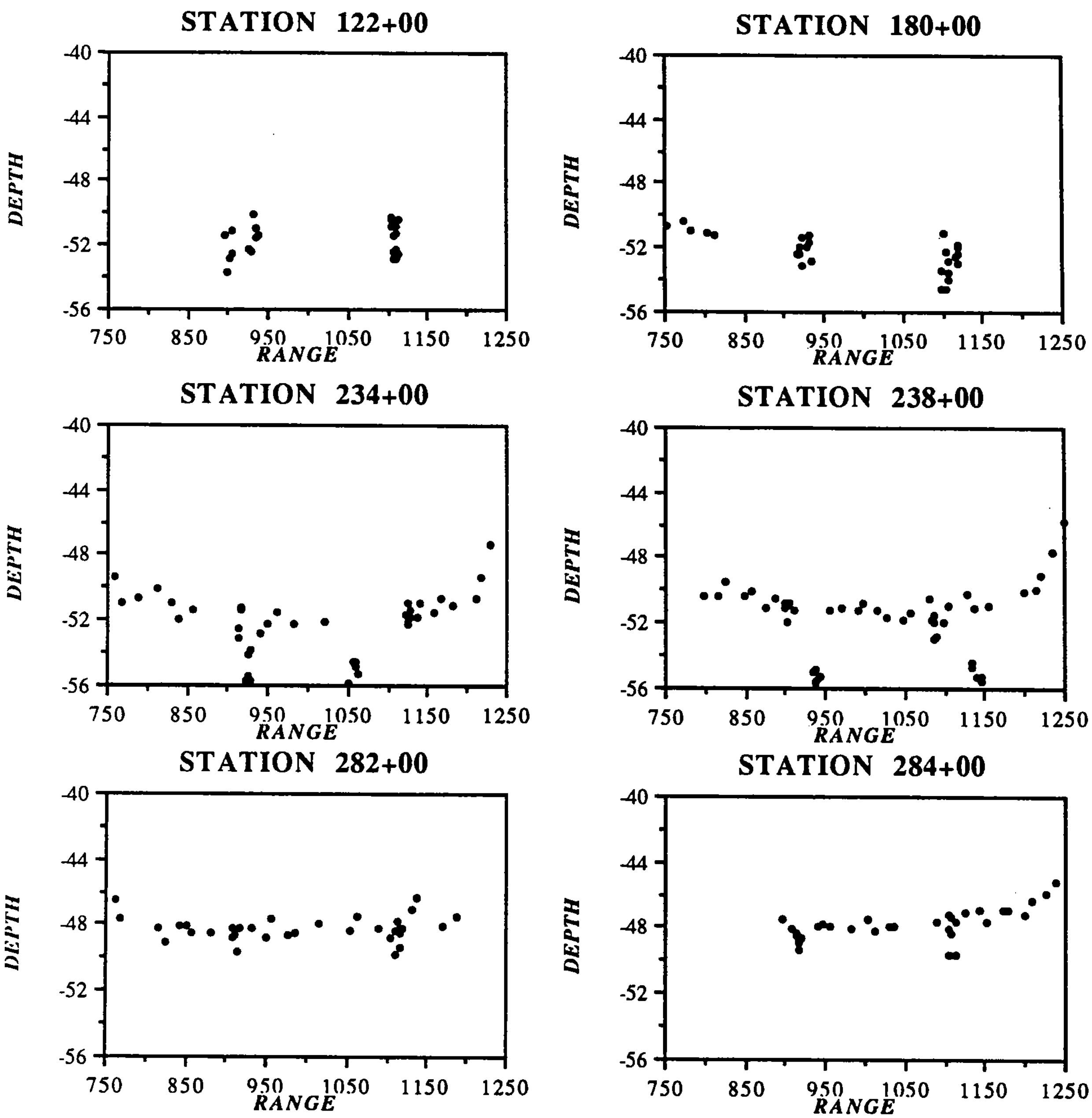


Figure G8. Range versus Depth for June, 1990

Datum: MLW

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16. Abstract (Limit: 200 words)

Repeated side-scan sonar and multi-frequency bathymetric surveys, accompanied by accurate, high resolution, and repeatable navigation, were conducted in the vicinity of a tidal inlet to define the length and time scales associated with bedforms and channel shoaling in a structured tidal inlet. The study site, St. Marys entrance channel along the Georgia/Florida border (Fig. 1), has a dredged channel approximately 46-52 feet in depth at a datum of mean low water (MLW), bordered by a large ebb tidal delta. The tidal inlet serves Cumberland Sound, Kings Bay, and associated waterways, providing a large discharge of water from the inlet that creates bedforms and channel shoaling, given the abundance of sand-sized sediment in the vicinity. The jettied inlet produces flows that are predominantly tidally-driven, whereas farther offshore the driving forces consist predominantly of waves and storm-generated flows. In the channel reaches (Table 1) between these two areas, combined wave/steady flows are present, creating a myriad of scales of bedforms and shoaling patterns, emphasizing the difference in these scales between the three different flow regimes. The results provide an important data base for quantifying shoaling processes and mechanisms in tidal inlet channels.

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bedform migration

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

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